DEVELOPMENT & TESTING OF METHODS FOR HABITAT, BIOTA, & FUNCTIONS OF NATURAL & HUMAN-IMPACTED WILDERNESS STREAM ECOSYSTEMS

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Development and Testing of Methods for Assessing the Habitat, Biota, and Functions of Natural and Human-Impacted Wilderness Stream Ecosystems.

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Introduction

Wilderness areas comprise 38.6 million hectares (95.4 million acres) of federally managed land, with 36% managed by the U.S. Forest Service and 41% managed by the U.S. National Park Service (Stankey and McCool 1995). In addition to providing preservation of species diversity, recreation, and aesthetic value, wilderness serves as a reference state for ecological systems. Wilderness areas presumably have had the least amount of impact from human activity and therefore represent natural conditions against which scientists may judge how such human activity affects ecological systems and processes. For this reason, understanding and monitoring wilderness systems are necessary for making proper management decisions. This study determined the feasibility of collecting biomonitoring data in remote wilderness streams using the methods of Davis *et al.* (submitted), and set the stage for evaluating the ability of a hierarchical analysis (Minshall 1994) to appropriately examine and characterize stream ecosystems for the purpose of ecological understanding and management.

Ecosystem Structure and Function

Ecosystem management requires natural resource managers to focus on whole ecosystems and processes in an effort to sustain ecosystem integrity (Overbay 1992; Kessler *et al.* 1992). Biomonitoring has become a common technique by which many resource managers use scientific methodology to characterize aquatic systems for purposes of ecosystem management and maintenance of water quality standards. This technique is best typified by stream benthic macroinvertebrate community analyses,

where community structure, diversity, and density are used to determine the present state of stream ecosystems (*e.g.* Plafkin *et al.* 1989). There are benefits to using the benthic macroinvertebrate community in analyses of biological integrity. Many members of the community are ubiquitous, sedentary, abundant, and reasonably well studied and understood (Rosenberg and Resh 1993). Additionally, most benthic macroinvertebrates have life cycles of one year or more, which allows for the integration of short-term environmental stresses. Benthic invertebrates also serve as a primary food source for many fish species of importance to managers. In addition to the invertebrate community, fish community analysis, water chemistry data, and physical habitat measures are used for characterization of aquatic systems.

Ecosystems, however, are by definition composed of both parts and processes, better termed structure and function, and integrity must be understood and preserved for both (Odum 1963; O'Neill *et al.* 1986; Karr 1993; Minshall 1994). Stream ecosystem structure includes composition and biomass of the biota, and the physical habitat templet upon which the ecosystem operates. Stream ecosystem function includes carbon and nutrient transport and retention, organic matter decomposition, and ecosystem metabolism. Both structure and function can operate independently toward maintenance of ecosystem stability, and so protection of structural integrity does not automatically imply maintenance of functional integrity, and vice versa (Rodgers *et al.* 1979; Kay 1991; King 1993; Steneck and Dethier 1994; Stone 1995).

Hierarchy

Ecosystems are complex systems and the study and understanding of such complex systems is facilitated utilizing hierarchical analysis (O'Neill *et al.* 1986; O'Neill 1989; Allen and Hoekstra 1992). Every complex system is composed of a heirarchy of levels, each level comprised of members of the one beneath (O'Neill *et al.* 1986). Any given level is constrained by boundary conditions set by the level immediately above, and constrained by limitations of the individual parts of the level below. In the scientific method, individual levels are studied by controlling for constraining higher-level factors and averaging across the variability of lower levels (O'Neill 1989). Once phenomena at a given level are identified, the lower level is examined to determine the mechanisms responsible for the observed patterns. The higher levels are then studied to establish the context and significance of the phenomena (Levin 1992; O'Neill *et al.* 1986).

Biomonitoring could make use of hierarchical analysis to better understand stream ecosystems. Monitoring could focus upon certain hierarchical levels of organization and find correlations and patterns. In aquatic systems, this process commonly is done at the level of invertebrate community structure, although diatom-algae and fish have also been used, and certain community responses are correlated with certain impairments. Using a hierarchical analysis, the next step would be to examine the levels below the community to determine the mechanism(s) for the responses and those levels above to determine the constraint(s) responsible for the observed patterns. An example of such an observed pattern would be a shift in invertebrate, algal, or fish community structure after logging or mining. After the pattern is observed, lower hierarchical levels could be examined to elucidate mechanisms, which might include individual species' responses to changes in

nutrient availability and physical or chemical habitat. Higher levels also could be examined for specific ways in which logging or mining disturbance may alter constraints such as total system productivity or available habitat. The understanding of mechanisms and constraints would allow responses to certain stresses to be predicted. The ability to predict responses to (rather than monitor the consequences of) specific management decisions would best enable managers to maintain ecosystem integrity (Minshall 1996).

Scale

Ecosystems exist and operate at many temporal and spatial scales, stream ecosystems being no exception (McIntire and Colby 1978; Frissell *et al.* 1986; Minshall 1994). These scales are also hierarchical and, because scales of management vary, scales of information upon which management decisions are made must vary also. There is no 'correct' scale at which to describe ecosystems (Levin 1992) and so ecosystem management requires first that the appropriate scale be determined for decision-making. For example, management concerns and subsequent decisions may encompass reach-scale fish habitat; stream-system and watershed-scale logging, grazing, or recreation; regional acid deposition; or global-scale climate change. As the scales of decision-making vary, multiple measures, each focusing on different scales and levels of detail and ranging from generic to site-specific, are required (Levin 1989). Progress has been made toward defining spatial scales relevant to stream ecosystem management (Frissell *et al.* 1986; Minshall 1994). The focus must now be upon determining relevant stream ecosystem properties to examine at these different relevant scales (Minshall 1988).

In an effort to determine feasible techniques of collection and analysis of wilderness stream data, data collection methods (Davis *et al.* submitted) and a hierarchical analysis of structure and function (Minshall 1994) were evaluated in a small suite of streams in the Frank Church River of No Return Wilderness Area. Collection techniques were scrutinized for their logistic and economic feasibility, and modified where necessary.

Our ultimate objectives were to determine (1) which measurements were necessary to adequately describe conditions in a stream, (2) which measurements were most sensitive to differences among streams, and (3) which measurements, if any, were redundant or extraneous. Achievement of this objective is dependent upon data, such as we present here, for a number of sites. Because of funding limitations, we only were able to complete measurements for three wilderness streams and so were unable to undertake a rigorous statistical treatment in addressing the above objectives. However, we have shown that the data required can be collected successfully and we have been able to put forth a number of common-sense recommendations for wilderness stream monitoring based on our findings.

Methods

Data collection

The procedures described by Davis *et al.* (submitted) were implemented in Cliff, Pioneer, and Rush Creeks within the Big Creek drainage in the Frank Church River of No Return Wilderness Area (FCRNRWA) in central Idaho. All three streams drain directly into Big Creek within 0.5 km of one another and are subject to similar climatic conditions

(Davis 1995). The elevations and exact locations are reported in Appendix A. These three streams are among a number of streams in the Big Creek drainage that have been under study since 1988 by the Stream Ecology Center at Idaho State University. Research has focused upon long-term biomonitoring and stream ecosystem recovery from wildfire (Minshall *et al.* 1994; Royer *et al.* 1995). Data obtained for methods development and evaluation were gathered during 1994 and 1995.

The hierarchical analysis (Minshall 1994) consists of a spatial hierarchical classification (Table 1) and four discrete stages of monitoring intensity, progressing from Stage I to Stage IV, with each stage comprised of several environmental and biotic 'factors' (Table 2). Techniques for the measurement of each specific factor are described by Davis *et al.* (submitted). All data collection followed procedures detailed in the methods manual with the exceptions of Stage I substrate size, Stage II magnesium, and Stage III solar radiation and hydraulic shear stress. Substrate size was quantified using a Wolman pebble count and simple statistics (mean and coefficient of variation [CV]) as dictated by the hierarchical analysis (Minshall 1994). Stage II magnesium was calculated using laboratory analysis values for hardness and calcium, and the equation:

$$\text{Hardness, mg } CaCO_3/L = 2.497 \text{ [Ca, mg/L]} + 4.118 \text{ [Mg, mg/L]} \tag{1}$$

Table 1. Spatial hierarchical classification of the Big Creek wilderness streams (after Frissell *et al.* 1986; Minshall 1994).

Stream Habitat (linear spatial scale)	Defining Measures	Big Creek Characteristics
Biogeoclimatic Region (10^5 m)	Regional climate	Northern Rocky Mountains Ecoregion, semi-arid Steppe; hot dry summers, cold snowy winters (Bailey 1989; Robinson and Minshall 1995)
	Regional geology	Central Idaho northern Rocky Mountains (Alt and Hyndman 1989)
	Regional topography	Narrow steep-sided canyons; forested mountain tops
	Regional terrestrial vegetation	Semi-arid steppe forest and grassland
	Flow regime	High snowmelt discharge, constant summer baseflow, rare summer spates
Stream System (10^3 - 10^4 m)	Local climate	74 cm precipitation annually, 54% between Nov. and Mar.
	Local geology	Precambrian metamorphic schists and gneisses with Cretacious and Eocene granitic intrusions of the Atlanta (Idaho) batholith (Alt and Hyndman 1989).
	Local topography	Cliff - southern aspect Pioneer - northern aspect Rush - northern aspect
	Local terrestrial vegetation	Douglas Fir and Ponderosa Pine; extensive areas of bare rock; open areas of sagebrush and grass.
	Thermal regime	Summer min/max of 9/20 °C (see Fig. 11)
Segment System (10^2 - 10^3 m)	Tributary junctions	Rush - between Lewis Creek tributary and confluence with Big Creek
	Major geologic discontinuities	Cliff - change from granite to schist/gneiss bedrock occurs above study reach Pioneer - none noted Rush - none noted
Reach System (10^1 - 10^2 m)	Channel slope	Cliff - 0.18 Pioneer - 0.25 Rush - 0.01
	Valley form	Cliff - narrow type A2 Rosgen (1994) classification Pioneer - narrow type A3 Rush - less confined type B3
	Bed material	Eroded cobble and gravel
	Riparian vegetation	Birch, alder, mountain maple, serviceberry

Table 2. Four-stage hierarchical sequence of stream environmental and biotic factors used in stream ecosystem biomonitoring analysis (from Minshall 1994).

STAGE I	Measurement per Feature	Purpose
ENVIRONMENTAL FACTORS:		
Temperature	24-hr. maximum and minimum during warmest month of year	Estimate of annual maximum and diel change (ΔT)
Discharge	Summer baseflow	Characterization of stream size; permit calculation of fluxes
Substratum	Mean and CV of x-axis for ≥ 100 randomly selected particles	Mean particle size distribution and heterogeneity
Alkalinity Hardness pH Specific conductance Turbidity	Grab samples analyzed using standard methods	General water quality
BIOTIC FACTORS:		
Macroinvertebrates	Rapid Bioassessment Protocol III	Biotic condition indicators community structure indices
Fish	Rapid Bioassessment Protocol V	Biotic condition indicators community structure indices
STAGE II		
ENVIRONMENTAL FACTORS:		
Solar radiation	Percent incoming PAR reaching stream surface at 9, 12, 3, and 6 on a clear day in summer	Relative density and shading by vegetative and topographic features
Temperature	Seasonal 30-d thermograph records	Improved characterization of thermal regime and heat budgets
Discharge	Seasonal instantaneous (5 random times each) measurements or 30-d stage height records	Improved characterization of flow regime
Substratum	Embeddedness and stability	Estimate of suitability of streambed for fish (egg) and invertebrate survival
Calcium Magnesium Nitrate-Nitrogen Phosphorus (ortho) Sulfate	Filtered sample Colorimetric field procedure	Delineation of main cations Principal plant nutrients Further delineation of primary anions

STAGE II (continued)	Measurement per Feature	Purpose
BIOTIC FACTORS:		
Algae	Periphyton chlorophyll and biomass	Quantification of an important food source and biotic indicator
Benthic organic matter	Total	Quantification of an important food source
Invertebrates	Total density Total biomass Analysis by functional feeding group	Improved indicators Estimate of 2° consumer production Definition of trophic organization

STAGE III		
ENVIRONMENTAL FACTORS:		
Solar radiation	Stream surface, mid-depth, and bottom PAR seasonally on clear days	Estimate of solar input
Temperature	Annual thermograph records	Characterization of thermal regime (Vannote and Sweeney 1980)
Discharge	Annual hydrograph records	Characterization of flow regime (Poff and Ward 1989)
Current velocity and depth	Measured at random locations throughout study area.	Characterization of stream habitat suitability; determination of hydraulic stress
Ammonia-nitrogen	Laboratory analysis of filtered samples	Further detail regarding nitrogen dynamics
Nutrient flux (N, P)	Concentration x discharge (with concentration determinations upgraded to laboratory quality)	Measure of resource availability
BIOTIC FACTORS:		
Algae	Diatom community metrics	Biotic condition indicator
Benthic organic matter	Partitioned into coarse and fine sizes and main sources	Refined food resource analysis
Transported organic matter/ invertebrate drift	Same as for Benthic organic matter	Estimate of exported organic matter and food available for filter feeders and fish
Leaf packs	Processing rates	Estimate of decomposition by microbial and invertebrate detritivores

STAGE III (continued)	Measurement per Feature	Purpose
1° production/community respiration	From colonized trays of substrata measured in recirculating chambers	Index of community P/R rates
Nutrient uptake	Nutrient addition uptake rates	Plant-nutrient growth status

STAGE IV		
ENVIRONMENTAL FACTORS:		
Solar radiation	Annual solar radiation	Determine solar radiation regime and energy input
BIOTIC FACTORS:		
Ecosystem P/R	Total-system metabolism using diel up/down or sum of individual component/compartment values	Measure of ecosystem behavior, productivity, and trophic state
Nutrient spiraling	Turnover length and time; index of retentiveness	Measure of ecosystem behavior and utilization/ retention efficiencies
Secondary production	Monthly measurements of invertebrate standing crops	Measure of impacts on fish-food producing capability of streams

(APHA 1992). For Stage III solar radiation, a submersible PAR meter was not available and so seasonal cumulative degree days are reported instead. Hydraulic shear stress (τ) was determined using the equation:

$$\tau = g\,S\,D\,\rho \qquad (2)$$

(Statzner *et al.* 1988), where g is acceleration due to gravity (cm/s^2), S is the slope of the water surface (dimensionless), D is water depth (cm), and ρ is the density of water (1g/cm^3). Water surface slope (S) for this study was total slope of the stream reach (channel slope, Table 2) measured using an inclinometer rather than hydrostatic leveling described by Davis *et al.* (submitted).

Snorkeling was determined to be the most suitable method for characterizing fish communities in wilderness streams, and direct enumeration was performed (Thurow 1994). The fish community was evaluated using metrics from RBP V (Plafkin *et al.* 1989), metrics developed for Idaho coldwater streams (Chandler *et al.* 1993), and metrics found to be important in streams of the northern Rocky Mountain ecoregion (NRM) where the Big Creek streams are located (Robinson and Minshall 1995). This was done in an attempt to determine which set of metrics was best suited for wilderness stream biomonitoring.

Salmonid biomass was calculated from visual estimates of fish length and a length-weight equation for rainbow trout (*Oncorhynchus mykiss*) generated from studies in the Firehole River in Yellowstone National Park (Carty *et al.* 1989). Size-estimation bias was determined by holding sticks of known length under water and having snorkelers estimate length. Sticks under 150 mm were routinely overestimated, and

sticks over 275 mm were routinely underestimated. A correction factor, based on observed bias, was determined and used to adjust estimated fish lengths prior to biomass calculations.

Diatoms from Cliff and Pioneer Creeks were collected and analyzed following methods of Robinson and Rushforth (1987) and Minshall *et al.* (1995). Community metrics were then scored using Montana Water Quality Bureau Protocol II (Bahls 1993).

Secondary production analysis deviated somewhat from procedures in the methods manual (Davis *et al.* submitted) and so is elaborated upon here. Five samples were taken each month from a 150-m study reach in each stream. Contents were preserved in the field in a 7% formalin solution and returned to the laboratory for processing.

All macroinvertebrates from each sample were handpicked under a dissecting microscope (10X) and identified to the lowest feasible taxonomic level. Body lengths were then measured to the nearest 0.2 mm using a stage micrometer. The large number of individuals in most taxa necessitated the construction of species-specific length-weight equations using weights obtained by subsampling, drying at 60°C, and weighing individuals from representative cohorts. The equations were then used to estimate the biomass of the remaining macroinvertebrates.

Annual production of all dominant taxa, except for Chironomidae and Simuliidae, was estimated using the size-length frequency method. A mean size-frequency distribution was calculated using the annual data set for each taxon, each division representing an individual cohort. The mean biomass lost between each successive

division was summed and divided by the duration (expressed in years) of the life cycle spent as part of the benthos (cohort production interval, CPI). CPIs were determined using size-frequency histograms. Production-to-biomass ratios (P/B) were calculated by dividing the annual production by the biomass. Seasonal mean P/B was calculated by dividing summed taxa production by summed taxa biomass.

Production of Chironomidae and Simuliidae was estimated using the models:

$$\log P = 0.43 + 1.052 \log B + 0.056\ T - 0.091 \log W_m \tag{3}$$

and

$$\log P = 0.693 + 0.98 \log B + 0.03\ T - 0.75 \log W_m \tag{4}$$

respectively, where P = mean annual biomass, T = mean annual water temperature, and W_m = maximum individual weight (from Benke 1993).

Seasonal production estimates were calculated from size-frequency distributions constructed from three-month intervals as follows:

Spring: April, May, June

Summer: June, July, August

Autumn: August, September, October

Winter: January, February, March

Winter production was not estimated for Pioneer Creek because data could not be collected. January data were not available for Rush Creek and so size-frequency distributions were constructed from two-month intervals. Chironomidae and Simuliidae production was estimated using the same intervals, but seasonal means were used in place of annual means for biomass and temperature.

Data Organization

Big Creek streams were first characterized according to the spatial hierarchy provided by Minshall (1994) (Table 1). Climate, geology, topography, and vegetation characteristics were obtained from maps and published sources. Flow regime was generalized for the biogeoclimatic region based upon regional and local climate. Thermal regime was not directly established at the stream-system scale (10^3-10^4 m) called for by Minshall (1994), but an annual thermograph was determined for the reach-system scale (10^1-10^2 m) as part of the hierarchical analysis. Some specific parameters of the flow regime were determined, but again for the reach system rather than for biogeoclimatic region. Segment-system parameters were determined using topographic and geologic maps. All reach-system parameters were measured in the field except for valley form, which was determined using topographic maps.

All data were organized into the four-stage hierarchical sequence (Table 2). An attempt was then made to determine if increased evaluation intensity better characterized reference stream ecosystems. This was done by examinating data progressively from Stage I to Stage IV and evaluating the ability of increased evaluation intensity and detail to further characterize stream ecosystems. Measures of ecosystem function also were evaluated for their feasibility in wilderness stream biomonitoring and for their application to ecosystem management.

Results

Cliff, Pioneer, and Rush Creeks were first classified using the spatial hierarchy (Table 1). All three streams share biogeoclimatic region characteristics, but differ markedly at the stream-system scale. Cliff Creek has a northern aspect, while Pioneer and Rush Creeks have a southern aspect. The thermal regimes of Cliff and Pioneer Creeks were similar, but Rush Creek had slightly larger daily and seasonal variation, further addressed in Stages I - IV of the hierarchical analysis. None of the streams had tributary junctions within the study reaches, and Rush Creek is 4th order, and Cliff and Pioneer Creeks are both 2nd order. Cliff Creek flows over a major geologic discontinuity, crossing from Cretaceous granite in its upper part onto the Precambrian schist and gneiss present in the study reach. Pioneer and Rush Creeks cross no geologic discontinuities, flowing over the same schist and gneiss bedrock (Alt and Hyndman 1989). Cliff and Pioneer Creeks have a much steeper slope than Rush but bed material and riparian vegetation are similar among all three. Using Rosgen (1994) classification techniques, Cliff and Pioneer Creeks both have entrenched, low sinuosity channels and differ only in channel materials (Cliff: A2 boulders; Pioneer: A3 cobble). Rush Creek has a moderately entrenched channel and moderate sinuosity and bed materials similar to Pioneer (B3 cobble).

In short, the three streams studied displayed a wide range of physical variability, including slope, aspect, and valley and channel width, despite close proximity and shared biogeoclimatic region. Such variability is inherent to stream ecosystems both within and among drainage basins and underlies the need for spatial classification.

Stage I

Simple physical measurements quantified the obvious fact that Rush Creek was much larger than Cliff and Pioneer. It had nearly an order of magnitude greater discharge and higher min/max temperatures than Cliff and Pioneer Creeks (Table 3). The maximum temperature of Cliff Creek was higher than Pioneer (Table 3), likely because of its southern aspect. These differences exemplified stream and segment system characteristics determined during the spatial hierarchical classification stage (Table 1). The wider channel of Rush Creek resulted in less shading, greater solar input, and higher summer temperatures than Cliff and Pioneer, which were smaller and cooler.

Mean substrate size was similar for the three streams, ranging from 13.9 - 19.5 cm (Table 3). Alkalinity ranged from 32-43 mg/L $CaCO_3$, hardness from 53-81 mg/L $CaCO_3$, and pH from 7.9 to 8. Specific conductance varied but was within the range typical of other wilderness streams in the Big Creek catchment (Royer *et al.* 1995).

Macroinvertebrate community metrics were calculated using RBP III (Table 4) and represent reference conditions for use in RBP III analysis (Plafkin *et al.* 1989). The RBP III scores streams with respect to reference conditions, and so does not explicitly score reference streams themselves. In a previous study of using comparable macroinvertebrate metrics in Northern Rocky Mountain streams, Cliff, Pioneer, and Rush Creeks all scored highly and were considered unimpacted. Rush Creek had highest total taxa and EPT taxa richness, to be expected of a 4^{th} order stream when compared to two of 2^{nd} order (Minshall *et al.* 1985).

Analysis of fish community metrics (Table 5) using RBP V scored all three streams as 'fair' (Table 6). The use of metrics adopted for Idaho coldwater streams

Table 3. Stage I environmental and biotic factors for Big Creek wilderness streams. References to figures apply to data for all three streams.

STAGE I	Cliff	Pioneer	Rush
ENVIRONMENTAL FACTORS			
Temperature			
July min/max	16.7/9	11.7/9	19.2/11
Baseflow Discharge (m^3/s)	.083	.088	.766
Substrate Size (cm)	19.5	13.9	13.9
CV	.84	1.09	.95
Alkalinity (mg $CaCO_3$/L)	34	42	32
Hardness (mg $CaCO_3$/L)	53	81	57
pH	7.9	8.0	8.0
Specific Conductance			
(μS/cm @20°C)	79	113	77
Turbidity (NTUs)	.98	.86	1.4
BIOTIC FACTORS			
Macroinvertebrates			
Rapid Bioassessment Protocol III		Table 4	
Fish			
Rapid Bioassessment Protocol V		Tables 5-6	

Table 4. Data used for the benthic macroinvertebrate Rapid Bioassessment Protocol III (Plafkin *et al.* 1989) Big Creek wilderness streams. Hilsenhoff regional tolerance values were obtained from Clark and Maret (1993).

METRIC	Cliff	Pioneer	Rush
Taxa Richness	28	22	30
Hilsenhoff Biotic Index	2.93	3.15	3.90
Ratio of Scraper/Filterer	9.2	11.9	6.9
Ratio of EPT/Chironomid	15.9	13.0	0.6
Percent contribution of dominant taxon	26.8	20.2	33.2
# EPT taxa	14	18	20
Percent Shredders	6.0	8.0	2.0

Table 5. Fish community data for Big Creek wilderness streams. Data were analyzed using the RBP V (Plafkin *et al.* 1989), protocols designed for Idaho coldwater streams (Chandler *et al.* 1993), and metrics for the northern Rocky Mountain ecoregion (NRM) of Idaho (Robinson and Minshall 1995).

Evaluation Method	Cliff	Pioneer	Rush
RBP V			
# Native species	2	1	2
# Sculpin species	0	0	0
# Native minnow species	0	0	0
# Sucker species	0	0	0
# Intolerant species	2	1	2
% Common Carp	0	0	0
% Omnivores	0	0	0
% Insectivores	100	100	100
% Catchable salmonids	0	0	0
# Individuals/km	176	72	132
% Introduced	0	0	0
% Anomalies	0	0	0
Chandler *et al.* (1993)			
# Native species	2	1	2
# Salmonid species	2	1	2
# Benthic insectivore species	0	0	0
# Intolerant species	2	1	2
% Salmonids	100	100	100
Total Biomass (g/m^2)	1.83	0.64	5.85
Salmonid Biomass (g/m^2)	1.83	0.64	5.85
% Young of Year	-	-	-
% Anomolies	0	0	0
Robinson and Minshall (1995)			
Salmonids/m^2	0.06	0.02	0.01
Salmonid biomass (g/m^2)	1.83	0.64	5.85

Table 6. Fish community metric scores for Big Creek Wilderness streams.

Evaluation Method	METRIC SCORE		
	Cliff	Pioneer	Rush
RBP V			
# Native species	1	1	1
# Sculpin species	1	1	1
# Native minnow species	1	1	1
# Sucker species	1	1	1
# Intolerant species	3	3	3
% Common Carp	5	5	5
% Omnivores	5	5	5
% Insectivores	5	5	5
% Catchable salmonids	3	3	3
# Individuals/km	5	3	5
% Introduced	5	5	5
% Anomalies	5	5	5
TOTAL SCORE	40	37	40
INTEGRITY CLASS	**Fair**	**Fair**	**Fair**
Chandler *et al.* (1993)			
# Native species	1	1	1
# Salmonid species	5	3	5
# Benthic insectivore species	1	1	1
# Intolerant species	3	3	3
% Salmonids	3	3	3
Total Biomass (g/m^2)	3	3	5
Salmonid Biomass (g/m^2)	3	3	5
% Young of Year	-	-	-
% Anomolies	5	5	5
TOTAL SCORE	24	22	28
MAXIMUM POSSIBLE	40	40	40
PERCENT SCORE	60%	55%	70%
CONDITION	Slightly Impaired	Slightly Impaired	Slightly Impaired
Robinson and Minshall (1995)			
Salmonids/m^2	5	1	1
Salmonid biomass (g/m^2)	3	3	5
TOTAL SCORE	8	4	6
MAXIMUM POSSIBLE	10	10	10
PERCENT SCORE	80%	40%	60%
CONDITION	Nonimpaired	Impaired	Slightly Impaired

(Chandler *et al.* 1993) gave results nearly identical to the RBP V (Table 6). Salmonid density and biomass were incorporated into metrics for the NRM ecoregion of Idaho (Robinson and Minshall 1995) and were similar among all three streams (Table 6). These densities were within the range of a previous estimate of fish in Big Creek itself (.02 to .21 fish/m^2) (Platts and McHenry 1988). However, Big Creek densities were based on trout and char alone, which potentially excluded the large number of mountain whitefish present now (author MTM , personal observation). Rush Creek had 3 and 6 times the biomass of Cliff and Pioneer Creeks, respectively (Table 5), indicating greater productivity, but was scored 'slightly impaired' because of the low density (Table 6).

All chemical and physical factors included in Stage I were similar among the three streams, and were similar for other wilderness streams in the same or nearby catchments (Robinson and Minshall 1995; Royer *et al.* 1995). Benthic invertebrate metrics were indicative of unimpacted streams and seemingly good biotic integrity. Taxa richness and EPT richness were comparable to other wilderness reference streams, and significantly higher than values found in nearby mining-impacted streams (Robinson and Minshall 1995).

Stage II

The three Big Creek streams differed with respect to the time of day of maximum photosynthetically active radiation (PAR) input (Fig. 1), but PAR at Rush Creek was an order of magnitude greater than the values for Cliff and Pioneer Creeks. This led to higher mean temperatures in Rush Creek during the summer, though all three streams had similar mean temperatures during both spring and fall (Fig. 2). The 3-4 fold increase of

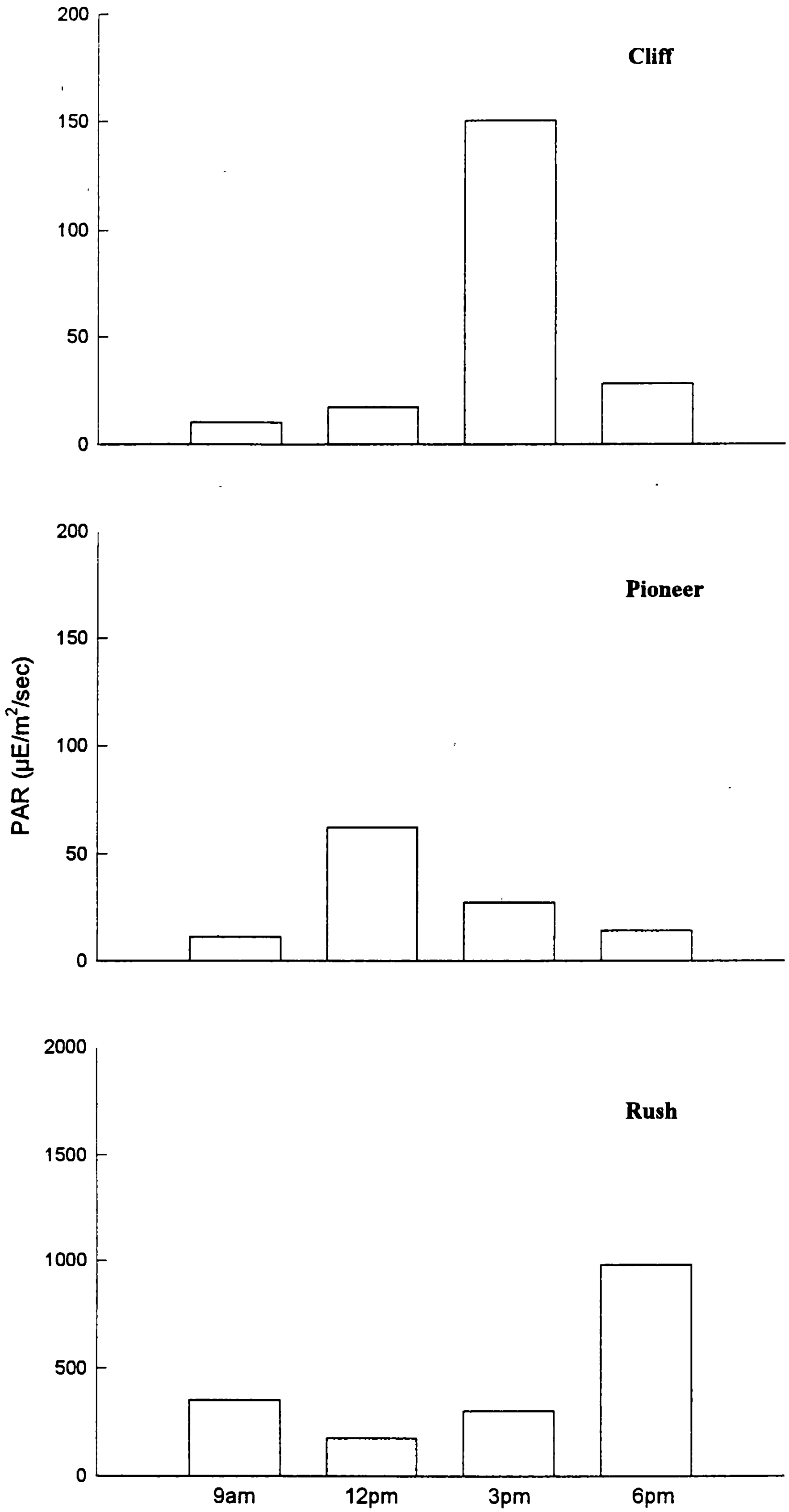


Figure 1. Stage II solar radiation measured as PAR reaching the stream surface throughout a single day in July 1994.

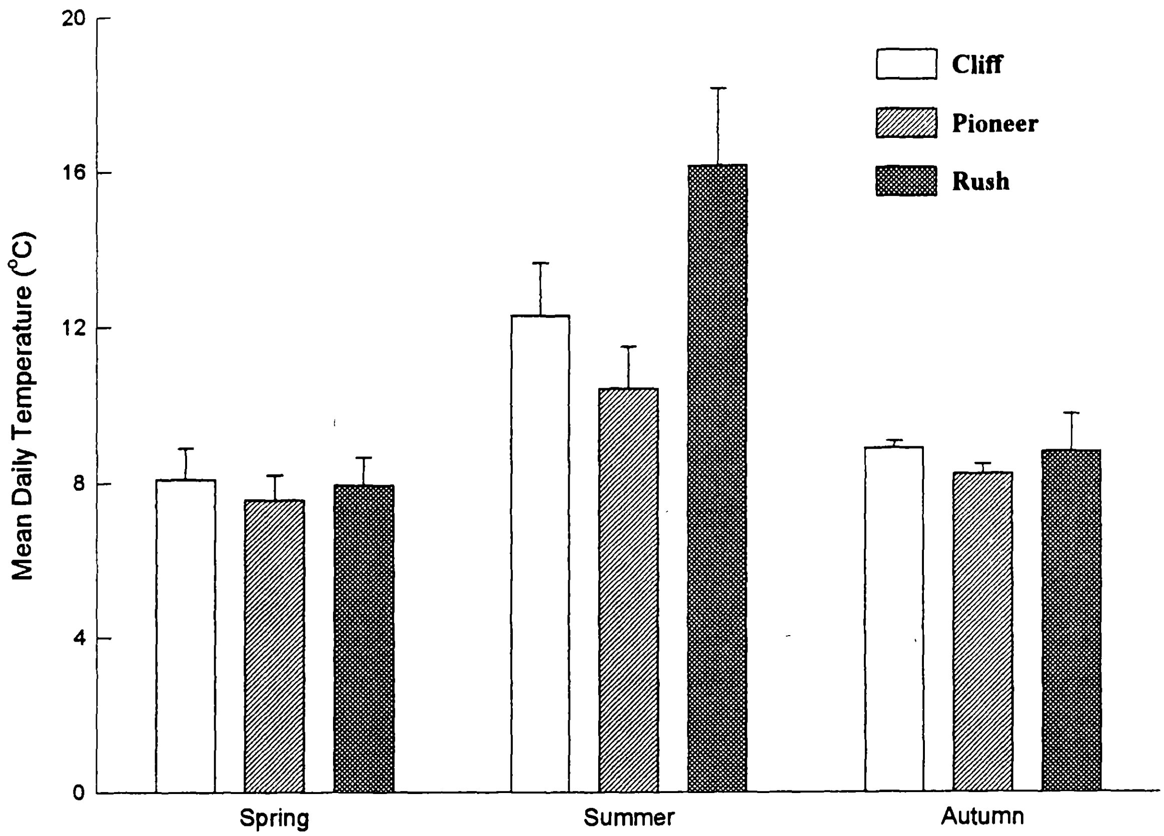


Figure 2. Stage II mean daily temperature by 1994 season for Big Creek streams. Mean daily temperature was calculated from hourly measures throughout each day. Error bars represent one standard deviation.

Rush Creek discharge during late spring/early summer was most likely the result of snowmelt. Cliff Creek showed similar snowmelt influence, although only a 2-3 fold increase. Pioneer Creek displayed no discernible snowmelt influence, but high snowmelt discharge may have been present in between sampling dates and missed (Fig. 3).

Mean embeddedness was similar among the three streams. A more complete chemical analysis, specifically for calcium and magnesium content (Table 7), accounted for differences in hardness observed in Stage I (Table 3). The greater value of hardness in Pioneer Creek was explained by high values of Ca and, more importantly, Mg, which contributes more to total hardness (Eq. 1).

Nitrogen (NO_3-N) concentration in Cliff Creek was an order of magnitude greater than in both Pioneer and Rush Creeks, though concentrations of phosphorus (PO_4-P) were similar for all three streams (Table 7). The resulting molar N:P ratio of 61 in Cliff Creek is typically indicative of phosphorus limitation (Allan 1995). Rush Creek was the opposite, having a low N:P, indicating nitrogen limitation. Sulfate levels were similar in all three streams.

Rush Creek had the greatest algal chlorophyll-*a* and AFDM. The low N:P ratio compared with Cliff and Pioneer Creeks was likely nullified by the much greater amount of PAR (Fig. 1). Rush Creek had less benthic organic matter (non-invertebrate AFDM from bethic samples) than either Cliff or Pioneer Creeks, which had similar amounts.

Benthic macroinvertebrate density ranged from 2500-6000 individuals/m^2 (Fig. 4) and biomass ranged from 800-3000 mg/m^2 (Fig. 5). Rush Creek had the highest values for both categories. Both of these ranges were within those from Big Creek and other wilderness streams reported in another study (Robinson and Minshall 1995).

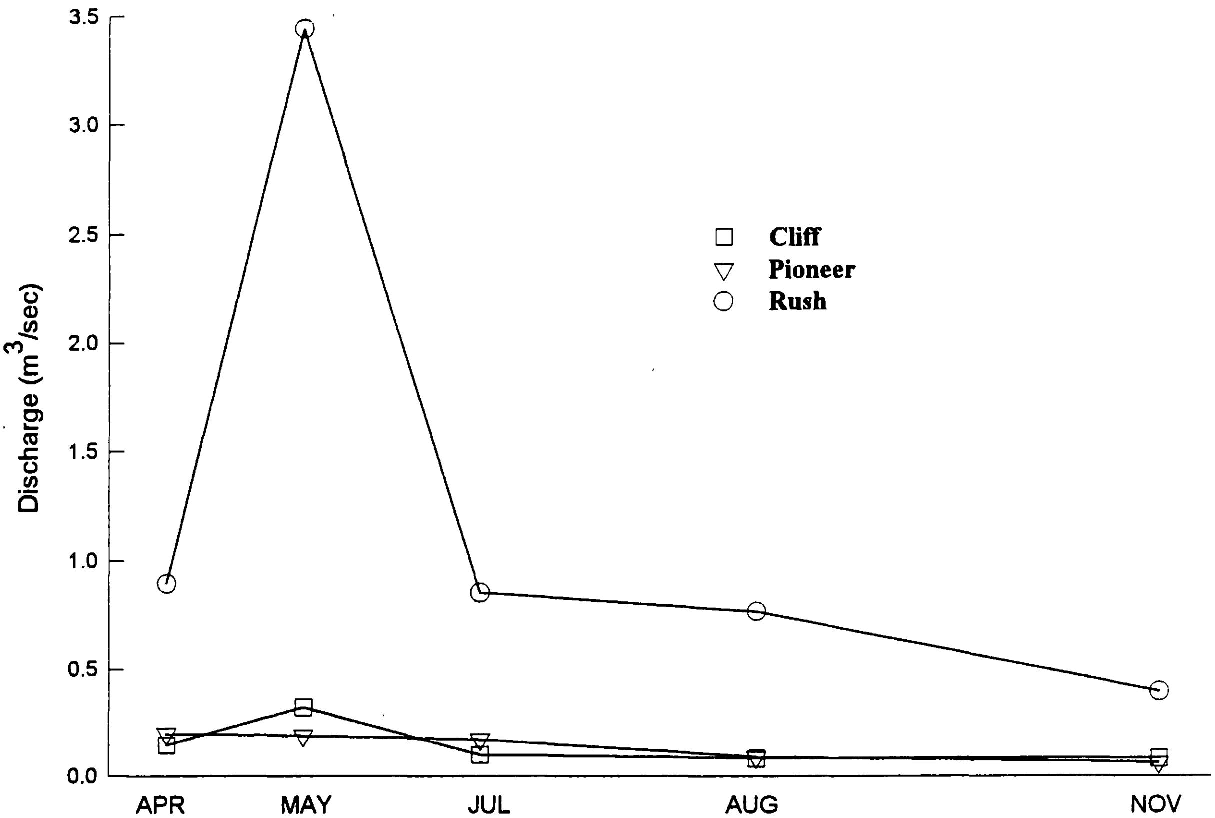


Figure 3. Stage II seasonal (1994) point measures of discharge for Big Creek streams.

Table 7. Stage II environmental and biotic factors for Big Creek wilderness streams drainage. References to figures apply to data for all three streams.

STAGE II	Cliff	Pioneer	Rush
ENVIRONMENTAL FACTORS			
Solar Radiation		Figure 1	
Temperature		Figure 2	
Discharge		Figure 3	
Embeddedness (%)	40.9	34.2	39.3
CV	.44	.53	.46
Ca (mg equivalent $CaCO_3$/L)	14	22	20
Mg (mg equivalent $CaCO_3$/L)	5	6	2
NO_3-N (mg/L)	0.35	.052	0.022
PO_4-P (mg/L)	0.012	0.005	0.01
N/P Ratio	61	23	4.4
Sulfate	2.79	2.32	2.21
BIOTIC FACTORS			
Algae			
Chlorophyll-*a* (mg/m^2)	8.8	2.8	10.7
AFDM (mg/m^2)	1810	1120	6940
Benthic Organic Matter (g/m^2)	26.18	26.7	14.51
Macroinvertebrates			
Total Density and Biomass		Figures 4-5	
Analysis by Feeding Group		Figures 6-7	

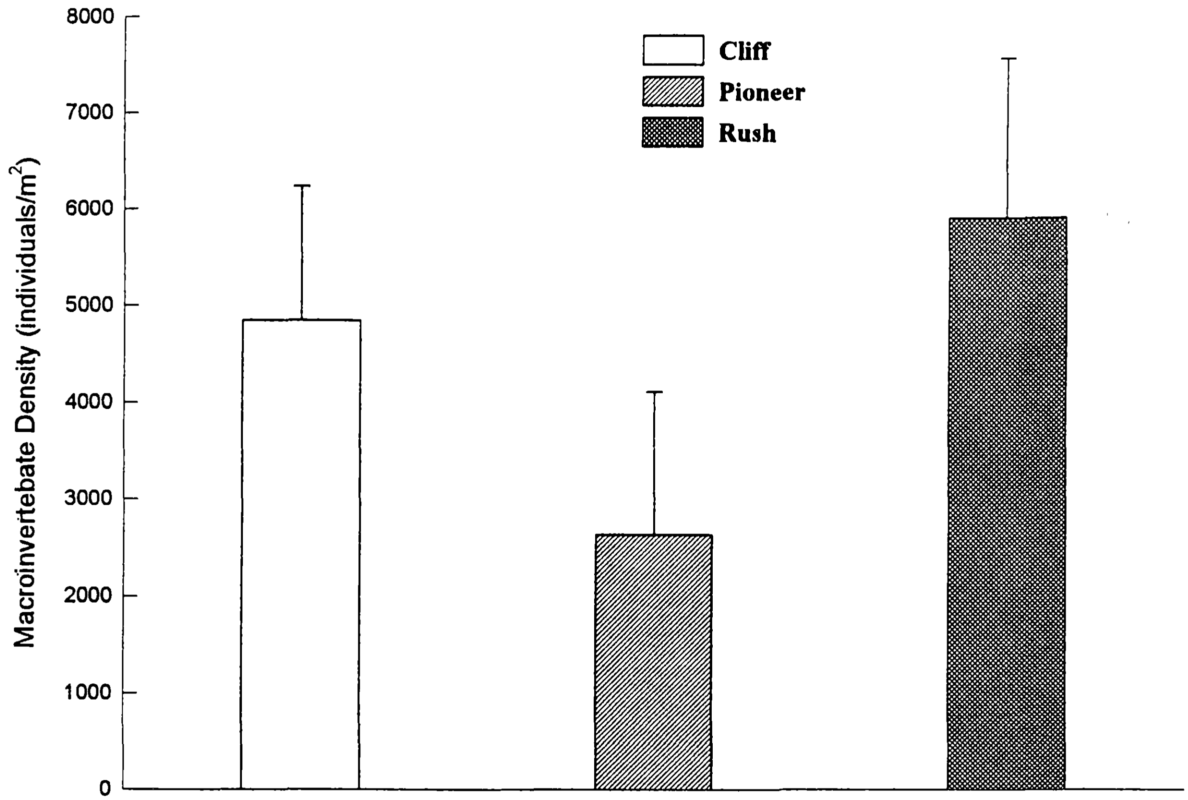


Figure 4. Stage II total macroinvertebrate density for Big Creek streams. Error bars represent one standard deviation (n=5).

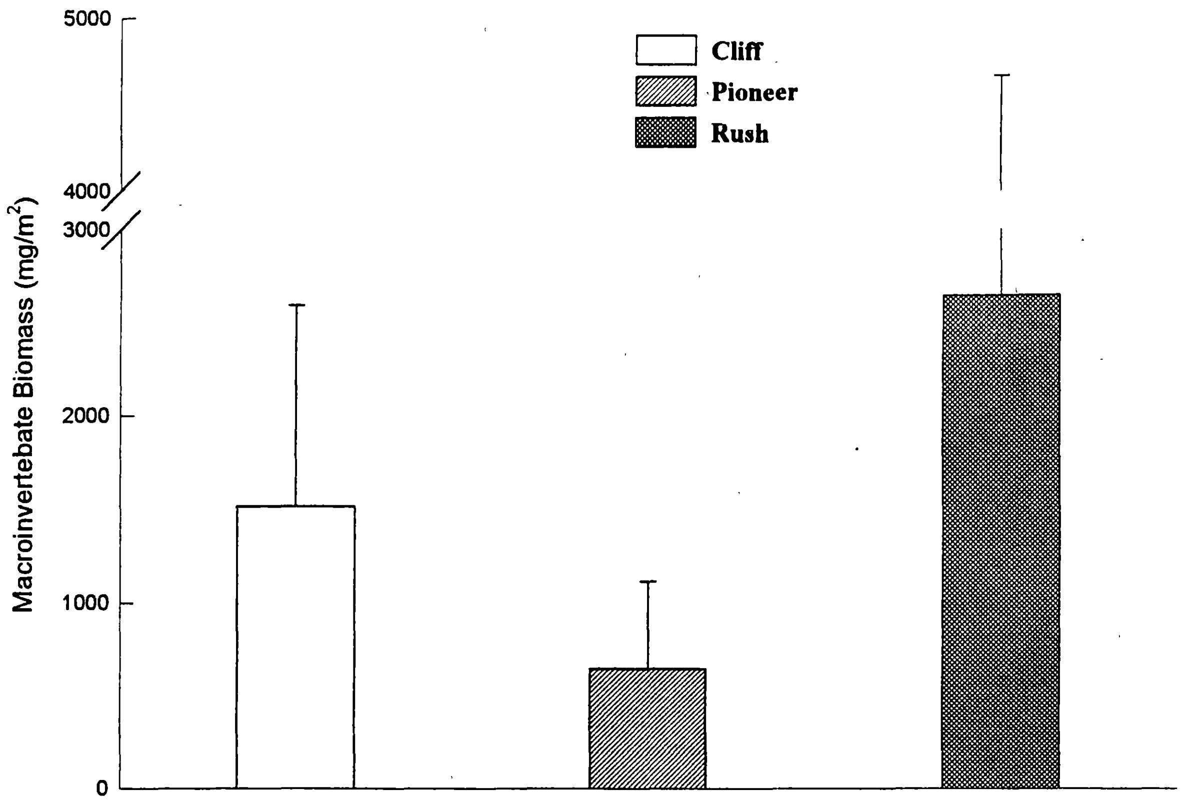


Figure 5. Stage II total macroinvertebrate biomass for Big Creek streams. Error bars represent one standard deviation (n=5).

Functional feeding group analysis showed miners and scrapers to numerically dominate streams, followed, in turn, by gatherers, predators, shredders, and filterers (Fig. 6). Filterers and scrapers dominated Cliff Creek biomass, but biomass was more equally distributed among feeding groups in Pioneer and Rush (Fig. 7)

In summary, stage II factors elicited differences among streams with respect to nutrients, showing Cliff Creek to have higher nitrate levels than the others, and subsequently a higher N/P ratio. Such differences were not apparent from Stage I analysis. Additionally, Stage II factors showed Rush Creek to be much more productive than Cliff or Pioneer. While production was not directly measured at this stage, larger amounts of algal and invertebrate biomass inferred greater production, likely a result of greater solar input (note Y-axes in Fig. 1).

Stage III

Rush Creek accumulated the greatest number of annual degree days because of its greater rate of heating during the summer (Fig. 8). Cliff Creek had slightly more degree days than the others in both spring and autumn and Pioneer was lowest in all seasons measured. The snowmelt influence and northern aspect likely caused Rush Creek to lag behind Cliff in spring accumulation, with aspect again a factor in autumn (Fig. 8). As a result, Rush Creek displayed the greatest temperature variation throughout the year (Fig. 9), typical of similarly-sized (orders 4-5) streams (Allan 1995; Vannote and Sweeney 1980). Cliff was warmer than Pioneer during the summer, the southern aspect facilitating more heat gain than the northern aspect. Current velocities were similar among reference

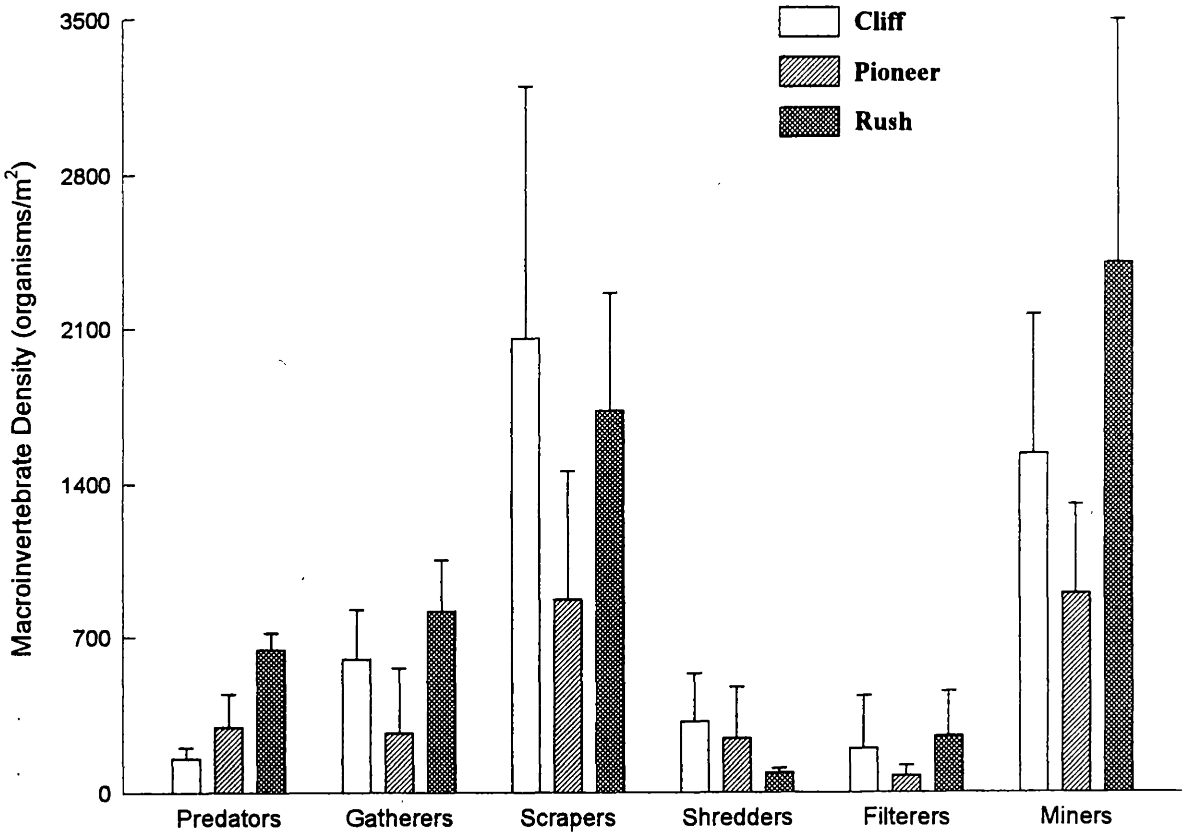


Figure 6. Stage II macroinvertebrate density partitioned into functional feeding groups for Big Creek streams. Error bars represent one standard deviation (n=5).

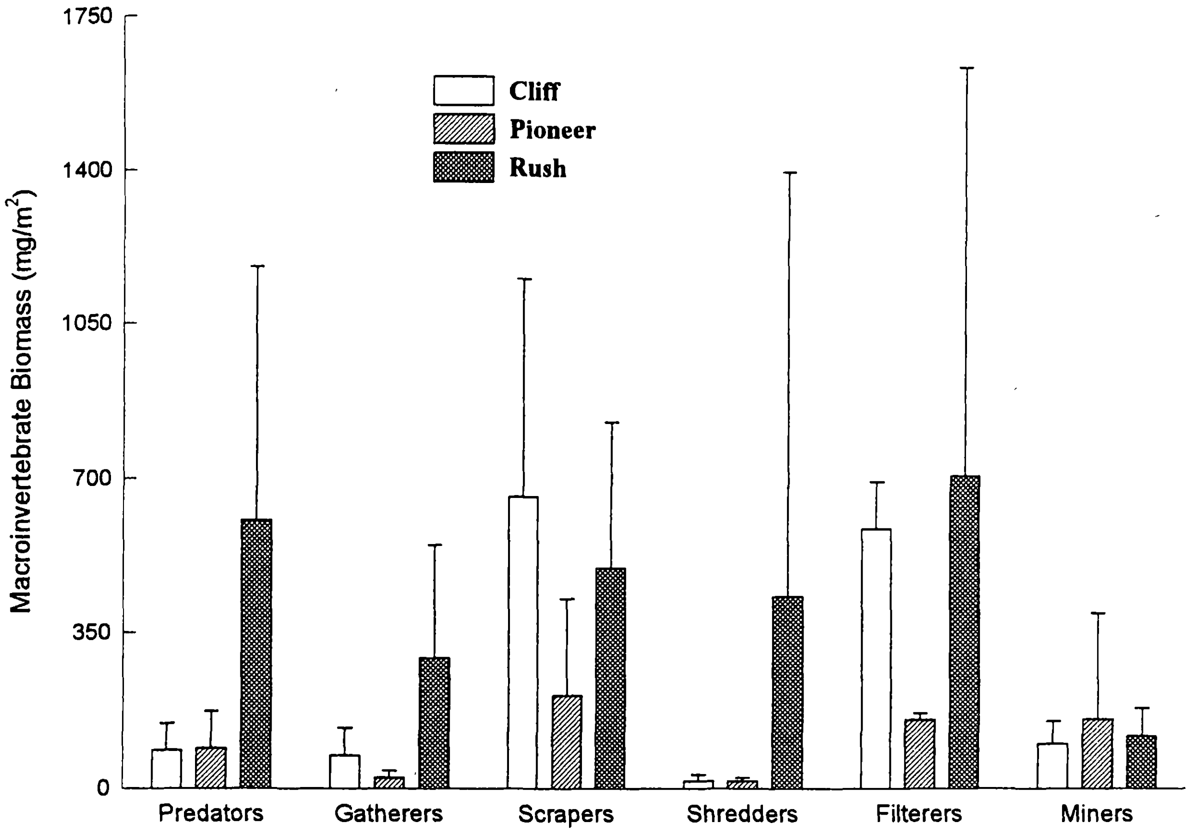


Figure 7. Stage II macroinvertebrate biomass per unit area partioned into functional feeding groups for Big Creek streams. Error bars represent one standard deviation (n=5).

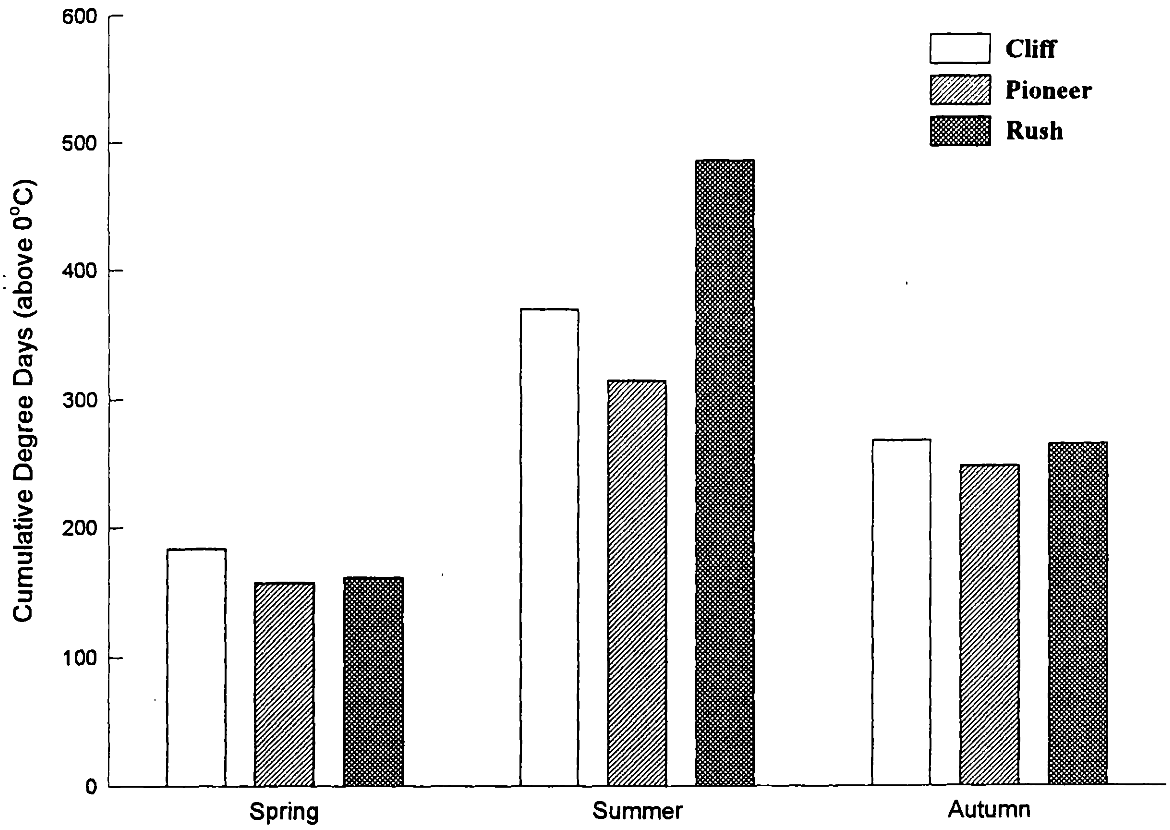


Figure 8. Stage III solar radiation as cumulative degree days for Big Creek streams measured seasonally during 1994.

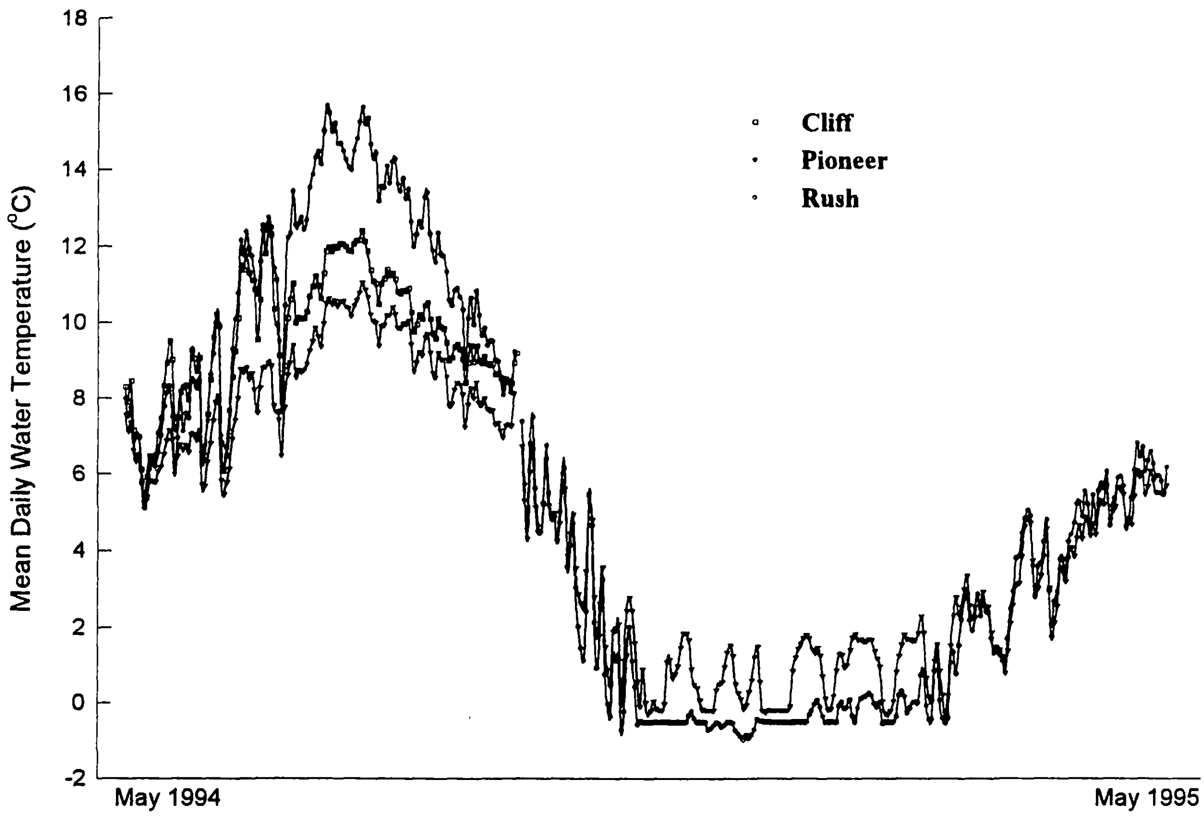


Figure 9. Stage III annual thermograph record for 1994-1995 for Big Creek streams. Cliff Creek data were available from only May to September because of a lost temperature probe. Mean daily values calculated from hourly readings throughout each day.

streams at baseflow, with depth (Table 8) and width accounting for the far greater discharge of Rush.

Pioneer Creek had the greatest mean hydraulic shear stress, as well as the greatest range of values throughout the reach (44, and 25-63 dyn/cm^2, respectively). Rush Creek had the lowest mean and range of shear stress values, and Cliff was intermediate. Stream slope (Table 8) was the dominant factor in determining shear stress (Eq. 2). Slope in this case was calculated using an inclinometer, but water surface slope measured using the methods of Davis *et al.* (submitted) gives finer resolution necessary for proper shear stress calculation. For spatial classification, properly scaled topographic maps, such as U.S. Geological Survey 7.5 minute quadrangles, can be used to calculate slope.

Ammonium-nitrogen concentration was the same for all three Big Creek streams (0.2 mg/L, Table 8) in contrast to the large differences in NO_3-N (0.022 - 0.35 mg/L, Table 8). These values for ammonium concentration were higher than normal natural concentrations, which typically range from 0.01 - 0.09 mg/l (Hendricks and White 1995; Valett *et al.* 1996). Nitrogen flux, the total amount of nitrogen (measured as NO_3-N) flowing past a given point per day, was similar for Rush and Cliff Creeks (Fig. 10), the high nitrate-nitrogen concentration in Cliff accounting for the similar flux despite much lower discharge. During the latter part of the summer, the large discharge of Rush Creek was offset by low nitrogen concentrations, and flux became similar among all three streams. Phosphorus flux (Fig. 11) was more closely related to discharge because of the similar concentrations among streams (Table 7). An analysis of diatom community metrics in Cliff and Pioneer Creeks showed Pioneer to have minor impairment related to siltation (Table 9). This was despite having lower substrate embeddedness (Table 7).

Table 8. Stage III environmental and biotic factors for the Big Creek wilderness streams. References to figures apply to data for all three streams.

STAGE III	Cliff	Pioneer	Rush
ENVIRONMENTAL FACTORS			
Solar Radiation		Figure 8	
Temperature		Figure 9	
Annual Hydrograph	-	-	-
Current Velocity at baseflow (cm/s (±1 SD))	13.4 (11.2)	17.2 (11.9)	14.7 (7.1)
Stream Slope (dimensionless)	0.18	0.25	0.01
Water Depth at baseflow (cm (±1SD))	20.9 (10.2)	18.0 (7.9)	26.2 (7.9)
Mean (range) Hydraulic Shear Stress (dyn/cm^2)	14 (2-30)	44 (25-63)	3 (2.5-4.4)
NH_4-N (mg/L)	0.2	0.2	0.22
Nutrient Flux		Figures 10-11	
BIOTIC FACTORS			
Algae		Table 9	
BOM	-	-	-
TOM		Figure 12	
Leaf Pack decay rate constant	0.8821	0.181	0.0715
Gross 1° Production (August) ($gO_2/m^2/day$)	0.624	0.624	1.64
Nitrogen Uptake Rate ($\mu g/m^2/min$)	449	246	-
Phosphorus Uptake Rate ($\mu g/m^2/min$)	84	34	-

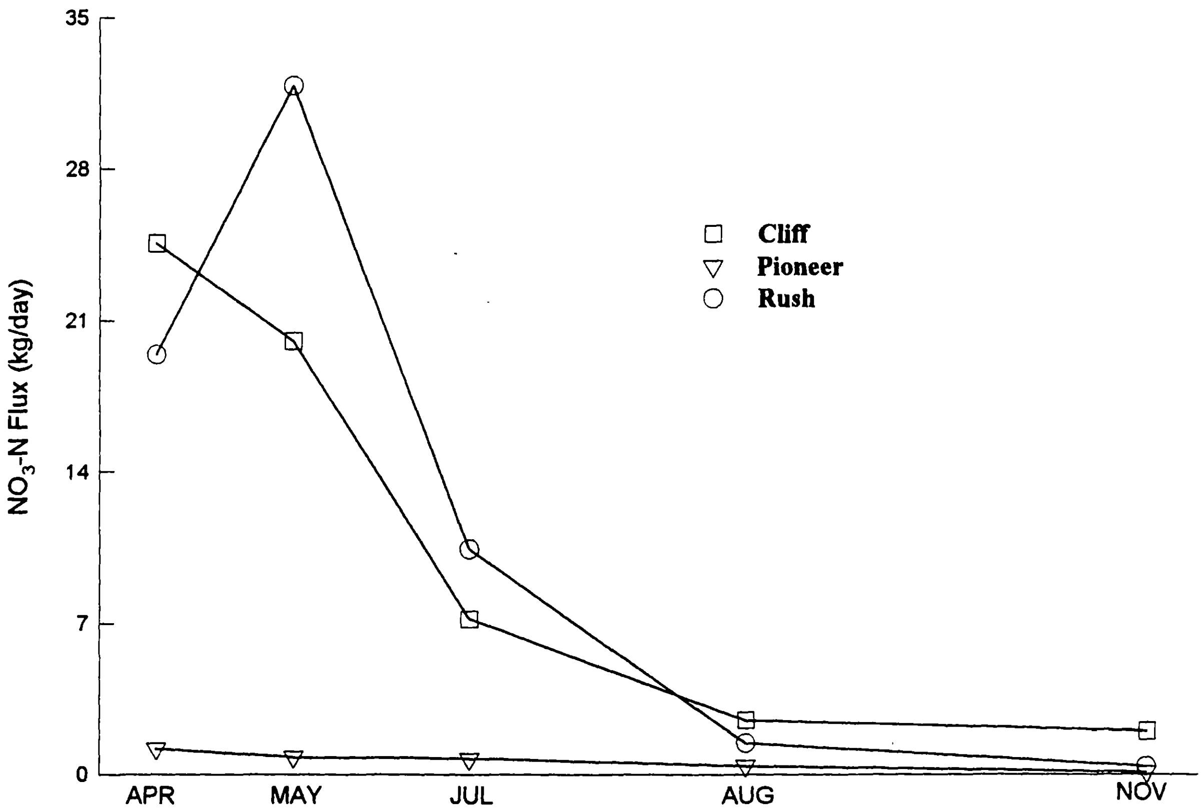


Figure 10. Stage III nitrogen flux (1994) calculated using nitrate-N concentration x stream discharge (see Figure 3).

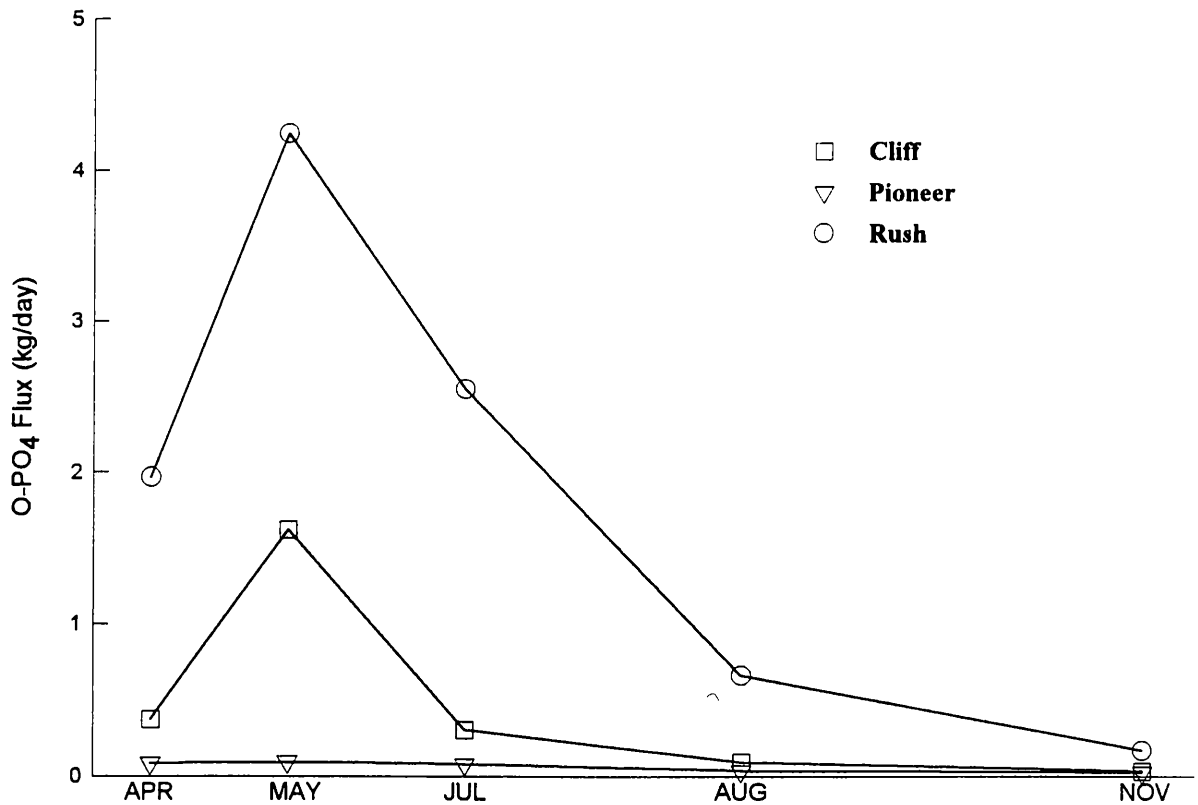


Figure 11. Stage III phosphorus flux (1994) calculated using PO_4-P concentration x stream discharge (see Figure 3).

Table 9. Stage III diatom metrics scored using Montana Water Quality Bureau Protocol II (Bahls 1993). Diatoms were not obtained from Rush Creek.

	Cliff	Pioneer
DIATOM METRIC		
Species Richness	35	25
Dominant Taxon	*Achnanthes lanceolata*	*Achnanthes spp.*
(%)	18.6	30.9
Simpson's Index	0.10	0.17
PRA		
Group 1	0	0
Group 2	28.4	33.2
Group 3	61.5	60
Pollution Index	2.7	2.5
Siltation Index	18	33.8
Navicula+Nitzschia		
IMPAIRMENT RATINGS		
Diversity	4	4
Pollution	4	4
Siltation	4	3
OVERALL IMPAIRMENT	None	Minor

The amount of organic matter in transport (TOM) was greatest in Cliff Creek and lowest in Rush (Fig. 12). Cliff Creek showed greatest annual variability of TOM concentration, ranging from 4 to nearly 40 gAFDM/m^3. Pioneer Creek ranged from 8-24 gAFDM/m^3, and Rush Creek had the lowest TOM concentrations, ranging from 6-12 gAFDM/m^3. Rush Creek TOM was at its lowest concentration during high discharge and so little annual variation was observed. These values were up to four orders of magnitude below TOM values previously reported for the Salmon River (Minshall *et al.* 1983); however, this previous Salmon River study included particles less than 50μm in size. It was this ultrafine particulate organic matter (UPOM) which dominated the TOM in the previous study, and because UPOM was not collected in the current study, TOM values are not comparable.

Leaf pack decay rates in Cliff were five times greater than in Pioneer and more than ten times greater than in Rush Creek. August gross primary productivity (GPP) was greater in Rush Creek (1.64 g O_2/m^2/day) than in Cliff and Pioneer, which were both the same (0.624 g O_2/m^2/day) (Table 8). The highest GPP occurred in Rush Creek and corresponded with the highest occurrence of standing algal biomass (Table 6), but algal standing crops were lower in Pioneer than Cliff (Table 7), despite having the same productivity. Rush Creek GPP was comparable to similar 4th order streams, and GPP in Cliff and Pioneer were also similar to other 2nd order streams (Davis 1995). Cliff had higher rates of both nitrogen and phosphorus uptake than Pioneer Creek (Table 8). These rates of nitrogen and phosphorus uptake were positively correlated with in-stream

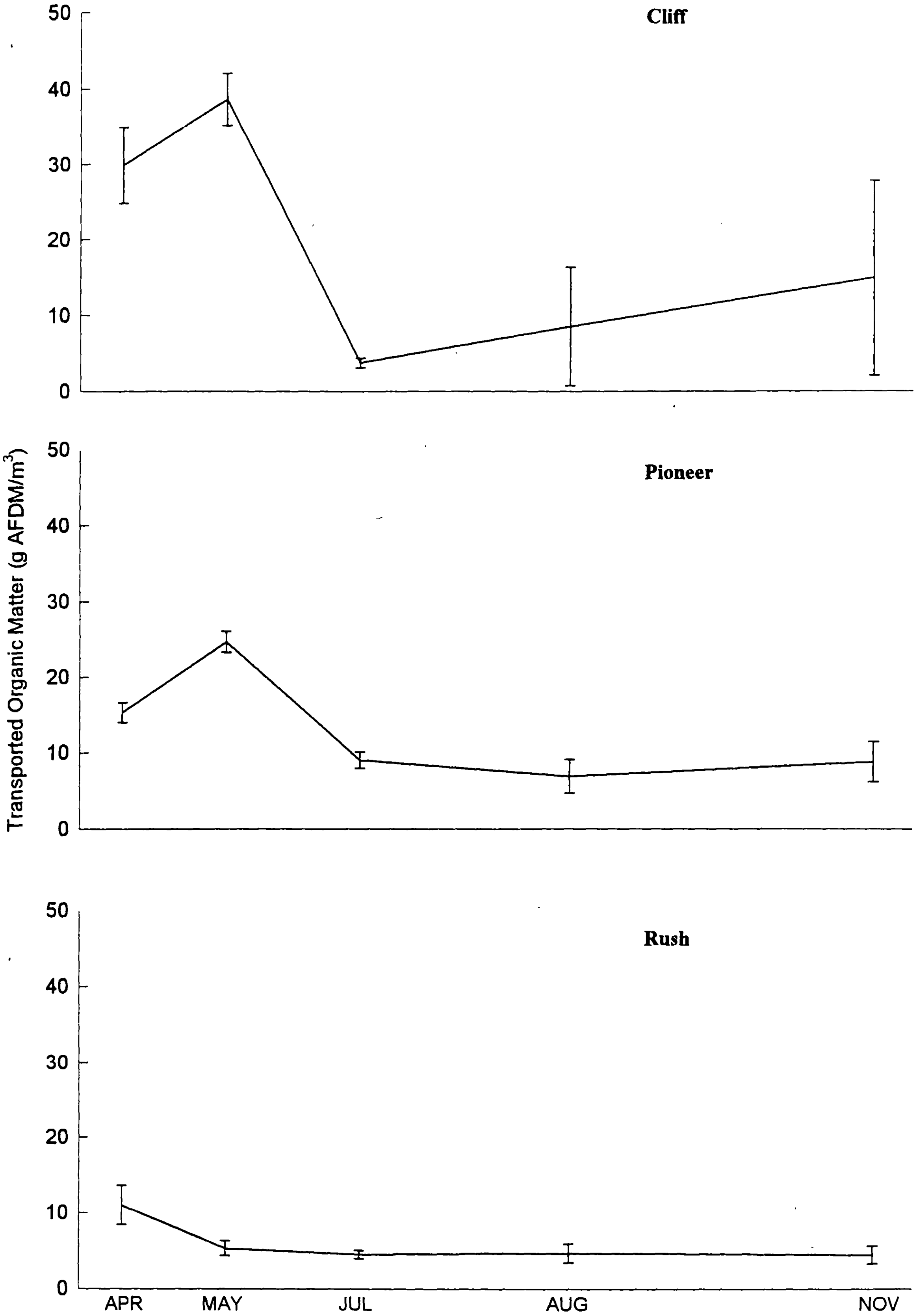


Figure 12. Stage III transported organic matter (1994) calculated using seston (AFDM) concentration x stream discharge (see Figure 3). Error bars represent one standard deviation (n=3).

concentrations, with Cliff Creek having the faster uptake rate and higher concentration for both nutrients (Tables 7, 8). Nutrient uptake rates were not measured in Rush Creek.

In all, Stage III physical measures did not strengthen the characterization of the three streams by further distinguishing among them. Factors such as solar input, cumulative degree days, and depth likely could have been predicted from knowledge that the streams differed in size. The first measurements of function did directly show Rush Creek to be more productive than Cliff or Pioneer (GPP), although slower leaf pack decay rates appeared anomalous at this stage. A lack of nutrient uptake rates precludes comparison of nutrient processing characteristics. Further measurements of functional parameters are required to properly judge their ability to help characterize streams.

Stage IV

Incoming solar energy was greater for Rush Creek than for Cliff and Pioneer (Fig. 13), coinciding with greater amounts of PAR (measured separately, Fig. 1), higher summer temperatures (Fig. 2), larger algal and invertebrate standing crops (Table 7), more summer and yearly cumulative degree days (Fig. 8), and higher GPP (Table 8). The southern and northern aspect of Cliff and Pioneer, respectively, was quantified by the greater solar input in Cliff from May to September. This was despite having similar vegetation cover (author MTM, personal observation). The size and open canopy of Rush Creek negated the effect of its northern aspect when comparing it to Cliff Creek.

Ecosystem metabolism (photosynthesis/respiration) during July 1994 showed both Cliff and Rush Creeks to be autotrophic (P/R >1) and Pioneer to be heterotrophic (P/R <1) (Table 10). Nitrogen uptake length was much longer in Cliff than Pioneer,

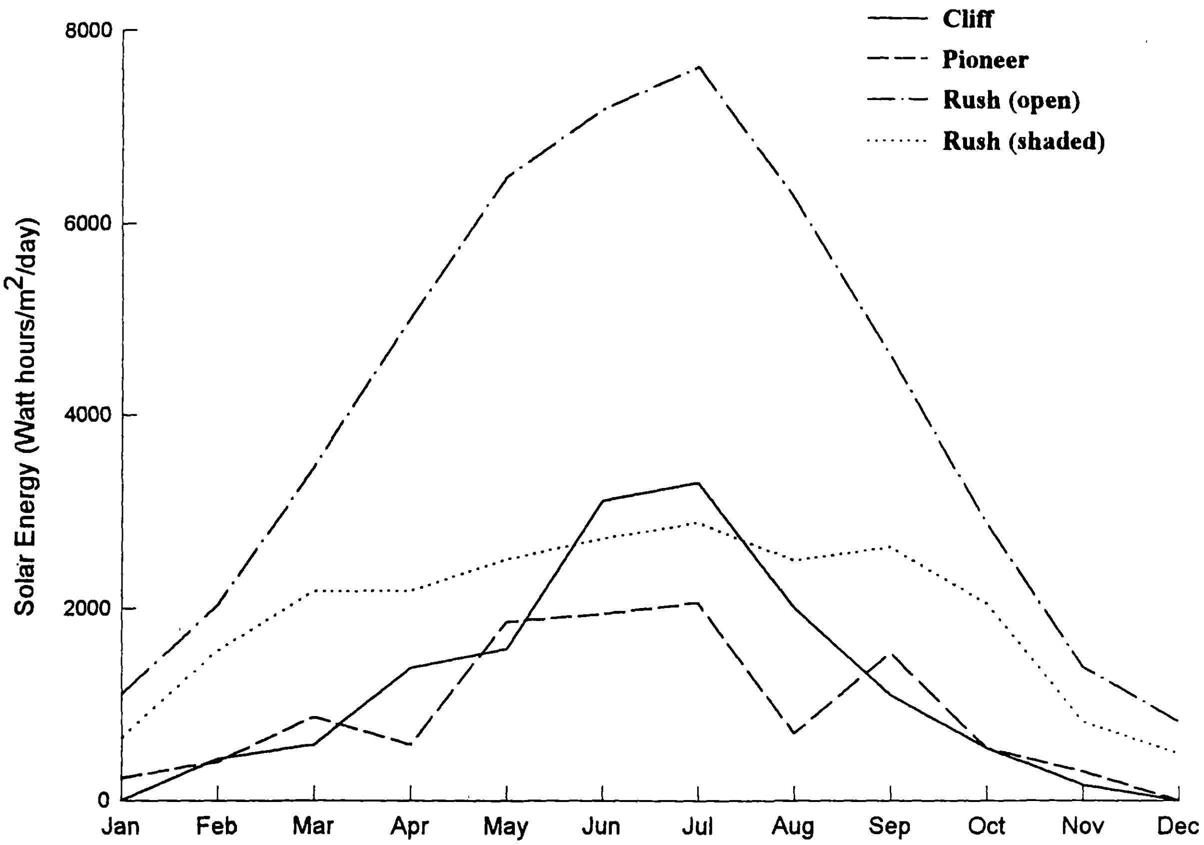


Figure 13. Stage IV 1994 annual solar radiation as determined using a Solar Pathfinder placed in the middle of each stream. Two distinctive segments of Rush Creek were measured separately.

Table 10. Stage IV environmental and biotic factors for unimpacted wilderness streams in the Big Creek drainage.

STAGE IV	Cliff	Pioneer	Rush
ENVIRONMENTAL FACTORS			
Solar Radiation		Figure 15	
BIOTIC FACTORS			
Ecosystem P/R (July)	1.79	0.7	1.44
Nitrogen Spiralling Uptake Length (m) (95% CL)	1839 (865-∞)	549 (279-1603)	-
Phosphorus Spiralling Uptake Length (m) (95% CL)	369.7 (272-579)	369.7 (272-579)	-
Secondary Production	Table 11	Table 12	Table 13

although phosphorus uptake lengths were identical. Rush Creek annual secondary production (12.4 g dry mass/m^2/yr) was greater than Cliff (4.9 g), which was greater than Pioneer (3.3 g) (Tables 11, 12, 13). This yearly trend held for secondary production during summer and coincided with standing crop biomass in July (Fig. 5), but not August primary production (Table 8). In Cliff Creek, greatest production occurred in summer, with progressively decreasing production in spring, winter, and autumn. Like Cliff Creek, Pioneer production was highest in summer, with decreasing production for spring and autumn. Winter production estimates were not available for Pioneer Creek. In Rush Creek, highest secondary production occurred in spring rather than summer, and was followed by summer, autumn, and winter production.

Yearly P/B ratios were highest in Rush Creek (5.84), with Cliff (5.21) followed by Pioneer (4.96) (Tables 11, 12, 13). Cliff and Pioneer ratios followed the same trend as production, with ratios greatest in summer and lowest in winter, (although winter values were not available for Pioneer Creek). Rush Creek, on the other hand, had the highest P/B ratio during winter, which was the period of least secondary production.

In some instances, the seasonal production was greater than the annual production (*e.g.* scraper production in Rush Creek during spring compared with the annual production). This was because shorter cohort-production intervals during a particular season resulted in greater biomass and growth rates for those individuals. To compensate, the percent annual production estimates were calculated using the seasonal total production as the denominator. In all three streams, scraper production contributed most to yearly production and was followed by filterer production.

Table 11. Seasonal and annual 1994 secondary production for Cliff Creek. All production values are mg dry mass/m^2/yr. Mean P/B calculated using Σ taxa production / Σ taxa biomass for each functional feeding group. Production and P/B for each taxon reported in Appendix C.

FEEDING GROUP	Annual Production	Spring Production	Summer Production	Autumn Production	Winter Production	Season Sum
PREDATORS						
Total Production	443	562	234	246	309	1351
Mean P/B	3.25	3.52	4.43	3.05	1.31	
% Annual Production		42	17	18	23	
GATHERERS						
Total Production	338	151	315	187	133	786
Mean P/B	4.29	2.01	2.39	2.88	1.9	
% Annual Production		19	40	24	17	
SCRAPERS						
Total Production	2676	2773	5068	1347	1307	10495
Mean P/B	7.05	3.89	5.94	6.98	7.64	
% Annual Production		26	48	13	12	
SHREDDERS						
Total Production	153	153	19	125	325	622
Mean P/B	4.53	4.66	2.08	3.83	5.57	
% Annual Production		25	3	20	52	
FILTERERS						
Total Production	1092	445	1922	1410	1567	5344
Mean P/B	3.81	6.64	9.64	5.19	3.98	
% Annual Production		8	36	26	29	
MINERS						
Total Production	161	283	116	50	180	629
Mean P/B						
% Annual Production		45	18	8	29	
TOTALS						
Production	4863	4367	7674	3365	3821	19227
Grand Mean P/B	5.21	4.07	6.12	5.2	4	
% Annual Production		23	40	18	20	

Table 12. Seasonal and annual 1994 secondary production for Pioneer Creek. All production values are mg dry mass/m^2/yr. Mean P/B calculated using Σ taxa production / Σ taxa biomass for each functional feeding group. Production and P/B for each taxon reported in Appendix C. No winter production estimates were available for Pioneer Creek.

FEEDING GROUP	Annual Production	Spring Production	Summer Production	Autumn Production	Winter Production	Season Sum
PREDATORS						
Total Production	425	215	541	248	-	1004
Mean P/B	2.92	1.81	3.97	1.47	-	
% Annual Production		21	54	25	-	
GATHERERS						
Total Production	156	155	153	108	-	416
Mean P/B	3.34	3.06	5.07	3.11	-	
% Annual Production		37	37	26	-	
SCRAPERS						
Total Production	1396	1426	1535	570	-	3531
Mean P/B	7.1	6.29	10.56	5.7	-	
% Annual Production		40	43	17	-	
SHREDDERS						
Total Production	205	67	97	540	-	704
Mean P/B		-	-	-	-	
% Annual Production		9	14	77	-	
FILTERERS						
Total Production	863	1087	947	1602	-	3636
Mean P/B	4.16	5.89	5.81	6.05	-	
% Annual Production		30	26	44		
MINERS						
Total Production	252	531	282	139	-	952
Mean P/B						
% Annual Production		56	30	14		
TOTALS						
Production	3297	3481	3555	3207	-	10243
Grand Mean P/B	4.96	5.43	7	4.95		
% Annual Production		34	35	31		

Table 13. Seasonal and annual 1994 secondary production for Rush Creek. All production values are mg dry mass/m^2/yr. Mean P/B calculated using Σ taxa production / Σ taxa biomass for each functional feeding group. Production and P/B for each taxon reported in Appendix C.

FEEDING GROUP	Annual Production	Spring Production	Summer Production	Autumn Production	Winter Production	Season Sum
PREDATORS						
Total Production	1716	2489	1814	2824	490	7617
Mean P/B	3.03	4.84	2.84	4.84	5.58	
% Annual Production		33	24	37	6	
GATHERERS						
Total Production	589	365	911	164	69	1509
Mean P/B	5.15	3.75	4.63	2.14	3.95	
% Annual Production		24	60	11	5	
SCRAPERS						
Total Production	5526	7205	4670	2792	2664	17331
Mean P/B	16.57	17.6	11.09	16.14	9.49	
% Annual Production		42	27	16	15	
SHREDDERS						
Total Production	325	536	165	119	78	899
Mean P/B	1.65	1.92	1.24	2.6	1.46	
% Annual Production		60	18	13	9	
FILTERERS						
Total Production	3401	2690	3526	2909	857	9982
Mean P/B	4.11	2.84	3.3	2.68	3.65	
% Annual Production		27	35	29	9	
MINERS						
Total Production	816	1113	2441	271	764	4589
Mean P/B						
% Annual Production		24	53	6	17	
TOTALS						
Production	12373	14398	13528	9079	4922	41927
Grand Mean P/B	5.84	6.1	5.26	4.57	6.14	
% Annual Production		34	32	22	12	

Discussion

Each stage of the stream ecosystem analysis encompassed both environmental and biotic factors, though specific emphasis varied with different stages. Environmental factors such as temperature, water chemistry, and physical habitat measurements, were examined in more detail and over longer time periods as analysis intensity increased, and biotic factors progressed from structural to functional emphasis with increasing analysis intensity.

Stage I environmental factors characterized streams by size and focused on water chemistry parameters such as conductivity, alkalinity, hardness, and pH. Biotic factors provided data comparable to those gathered using most bioassessment techniques (*e.g.* IDEQ 1996), namely the analysis of invertebrate and fish community metrics. Stage II environmental factors included more in-depth chemical analyses and provided measures of physical habitat. Biotic factors quantified standing crops of both primary producers and invertebrates, and measured benthic organic matter, a food resource for many invertebrates and other detritivores. Stage III factors extended temporal scales of analysis, monitoring yearly temperature patterns and seasonal nutrient and organic matter flux. Stage III factors also began to directly investigate and quantify biotic function, specifically gross primary production (GPP), leaf decomposition, and nutrient uptake rates.

Stage IV analysis added a final physical measure, namely a yearly estimate of solar input using a Solar Pathfinder. Benthic invertebrate secondary production was

calculated and all other Stage IV analyses were functional, encompassing algal respiration (allowing for P/R ratio calculation), and nitrate and phosphate uptake lengths.

Environmental Factors

Stream size was an important characteristic of streams, influencing factors such as yearly temperature patterns, solar input and primary and secondary productivity. PAR was an order of magnitude greater in Rush than in Cliff and Pioneer Creeks because of a wider channel. Seasonal differences in temperature were not as pronounced as the differences in incoming solar radiation. This disparity probably indicates that Rush Creek integrates a larger number of smaller watersheds of varying temperature, and could be influenced more by snowmelt than groundwater inputs (Vannote and Sweeney 1980).

Calcium and magnesium analysis of Big Creek streams provided little additional information than Stage I total hardness other than showing that calcium contributed the most cations. Sulfate concentrations showed little variability in the streams.

Stage III ammonium-nitrogen concentrations comprised 36%, 80%, and 90% of total inorganic nitrogen (assuming nitrate-nitrogen levels were negligible) in Cliff, Pioneer, and Rush Creek, respectively. Ammonium-nitrogen concentration typically is near 15% of total concentration (Allan 1995), although the percentage may be higher in streams where anoxic hyporheic processes release nitrogen to the water column in this reduced form. In such streams NH_4-N can comprise 14%-77% of total inorganic nitrogen (Hendricks and White 1995; Valett *et al.* 1996). The high absolute and relative concentrations of NH_4-N warrant further investigation, as the values were higher than

expected and there are no other known measurements of NH_4-N concentrations from Idaho wilderness streams.

Stage III measurements of current velocity and hydraulic shear stress (τ) provided detailed analysis of the hydraulic habitat available to benthic invertebrates. The variability of shear stress seemingly would be indicative of habitat heterogeneity and could influence species diversity. In these three wilderness streams, however, lowest taxa diversity was observed in Pioneer Creek (Table 4), which had the greatest range of shear stress, and the highest diversity was found in Rush Creek, which had the smallest shear stress range. Possibilities are that absolute τ was more important than the spatial heterogeneity in determining community diversity, or that the slopes, which strongly influence τ, were inaccurately determined using an inclinometer. Pioneer had the highest absolute hydraulic shear stress and lowest diversity, and Rush had the lowest hydraulic shear stress and greatest diversity. Cliff Creek had intermediate values for both.

The final environmental factor evaluated was Stage IV solar radiation. The amount of incoming solar energy accounted for a large amount of the observed separation of Rush from Cliff and Pioneer Creeks. Specifically, it helped explain why PAR, summer temperatures, productivity (as biomass and GPP), and cumulative degree days were so different in Rush Creek than in either Cliff or Pioneer.

Biotic Factors - Structural Properties

The analysis of biotic factors progressed from community metric analysis and autotrophic standing crop measurements to determination of primary and secondary

production and nutrient spiraling parameters. Stage I examined community metrics of the benthic invertebrates and fish. The RBP III has yet to be tested for its ability to detect more moderate degrees of impairment in streams of this area and must be refined to suit particular ecoregions. Benthic macroinvertebrate metrics refined for use in the northern Rocky Mountain ecoregion (NRM) are not yet complete (Robinson and Minshall 1995) but should be implemented once available. In another study in southwestern Oregon, the original RBP III poorly differentiated between reference and moderate logging impacts, but was fine tuned to include ten reliable metrics indicative of disturbance (Fore *et al.* 1996).

In addition to incorporation of refined metrics, benthic invertebrate assessments must incorporate predictable changes that occur in the community along the continuum from smaller to larger (lower to higher order) streams (Minshall *et al.* 1983). Knowledge of such predictable patterns must be applied to biological monitoring during either the site selection phase or data analysis phase (Tables 1 and 2). Localized phenomena superimposed on the continuum, such as high filter-feeder densities in lake outlet streams (Richardson and Mackay 1991), must be understood and incorporated as well.

This study allowed for the direct comparison of three protocols for evaluating the fish community in three wilderness streams: the RBP V refined for the Willamette River in Oregon (Plafkin *et al.* 1989), a protocol developed for Idaho coldwater streams (Chandler *et al.* 1993), and metrics developed for streams in the NRM ecoregion (Robinson and Minshall 1995). Neither the RBP V nor the Idaho protocol (Chandler *et al.* 1993) distinguished among the streams, scoring them all slightly less than pristine. The metrics shown important in the NRM ecoregion (Robinson and Minshall 1995) made

distinctions among all three streams, scoring Cliff as pristine or unimpaired, Rush as slightly impaired, and Pioneer as impaired. The disparity of biomass and density scores in Rush Creek could be the result of differences in stream productivity or the difficulty in snorkeling streams the width of Rush Creek. Snorkeling large streams is addressed in the modifications section.

While the life spans and mobility of fish make them seemingly good biomonitoring organisms, many characteristics of the fish communities in Idaho and surrounding states confound the information gained from fish community analyses. Many Western streams are stocked with salmonids, typically non-native species such as rainbow, brown (*Salmo trutta*), or brook (*Salvelinus fontinalus*) trout. Such stocking can result in unnaturally high densities and can occur in areas too degraded for them to occur naturally. As a result, fish density and biomass metrics may provide poor estimates of food availability and recruitment. Additionally, species diversity is naturally low in Western coldwater streams, hindering multi-metric analyses such as RBP V. Lastly, several salmonid species are marine for part or most of their lives and are affected by marine environmental conditions, harvest, and downstream river regulation.

Moving from standard community metrics to a wider range of biological characteristics, Stage II estimated productivity of streams using the structural measures of invertebrate, BOM, and algal standing crop biomass. All of these resources are measures of available food to other trophic levels (higher or lower). Invertebrate density and biomass gave an indication of relative productivity of the streams not implicit in RBP III analysis. Specifically, Rush appeared more productive than Cliff and Cliff more productive than Pioneer, based upon standing crop biomass measures.

The final structural evaluation of the biota was of the Stage III diatom community metric scoring. The metrics indicated different substrate characteristics in Cliff and Pioneer Creeks than measured by embeddedness (Table 7). The siltation impairment indicated by Pioneer Creek diatoms was opposite of the measured embeddedness. This may be evidence that embeddedness is a property of sand-sized particles and filling of interstitial spaces. Siltation may encompass silts and clays deposited on the stream bed and may be a better indicator of invertebrate habitat quality. High siltation can occur where embeddedness is low because of the different hydrology required for transport of the different sized-particles. The use of diatoms as biological indicators may be advantageous, as a study of rivers of England and Scotland showed diatom metric scores to be stable among all seasons during the year (Kelly *et al.* 1995). Seasonal variability among diatoms and other metrics (*e.g.* macroinvertebrates) is not well known, primarily because most biological monitoring occurs during the summer. Until seasonal variability of metrics is better understood and quantified, it would be beneficial to make comparisons among different streams sampled in different seasons only using metrics for which seasonal variability is known to be minimal. Unfortunately, seasonal variability of most metrics is poorly understood and must be a priority for biomonitoring research (Robinson and Minshall 1995).

Biotic Factors - Functional Processes

Stream ecosystem functional parameters were measured in Stages III and IV of the hierarchical analysis, with empirical determinations of primary and secondary productivity, nutrient spiraling parameters, and decomposition rates. Stage III analysis

consisted of component measurements of ecosystem function, specifically of GPP and nutrient uptake rates of algal-colonized trays placed in recirculating chambers (Davis 1995). Leaf litter decomposition rates were also measured. Stage IV measured respiration of the same algal-colonized trays as well as whole-stream nutrient uptake lengths and benthic secondary production.

GPP is a direct measure of the rate at which an ecosystem uses solar energy to produce biomass, and is therefore dependent on the amount of available solar energy and nutrients. The identical GPP occurring in Cliff and Pioneer Creeks during August did not reflect the differences in solar input , nutrient concentrations, or July invertebrate and algal biomass. This disparity could be the result of either greater grazing in Pioneer Creek or greater physical loss due to sloughing, but the exact explanation is unknown. The values obtained were within the productivity range of other streams in this region of Idaho (Davis 1995), showing that the technique was successfully performed in wilderness streams and that relevant GPP estimates were obtained, and so further investigation, consisting of multiple measures, is needed.

Uptake and decomposition are components of the overall process of nutrient cycling. The spatial and temporal bounds of such cycling help to physically define an ecosystem and so must be understood to properly characterize stream ecosystems. The ability to retain and cycle nutrients is necessary for the maintenance of ecosystem integrity and can be quantitatively measured for both whole stream systems and for individual component parts. This study showed the measurements of such functional measures to be possible in wilderness streams, but a lack of comparable data from impacted streams precludes their use as indicators of ecosystem integrity for the present.

Leaf pack decay rates were highly variable among reference streams. This variability requires further investigation, but is most likely the result of Cliff Creek having higher temperatures than Pioneer Creek and possibly differences in the invertebrate communities. The relatively greater decomposition rate indicates much more rapid processing of nutrients and organic matter in Cliff Creek than in Pioneer or Rush. Such rapid recycling of nutrients indicates inherent ecosystem stability, but this does not mean that Pioneer and Rush Creeks are unstable relative to Cliff because the range of natural variability in wilderness streams is unknown.

Stage IV functional analysis measured uptake length, a characteristic of nutrient cycling unique to streams. Nutrient cycling is constantly displaced longitudinally by downstream movement of water, and so a primary parameter of nutrient retention is uptake or spiraling length (Newbold *et al.* 1981). Measurements of total spiraling length incorporate both longitudinal displacement and biotic uptake, the parameters most important to estimates of whole-system nutrient retention. Nutrient retentiveness is an index of ecosystem function, with low retentiveness indicating inefficient cycling caused by a lack of functional stability. Functional instability, in turn, indicates poor ecosystem integrity.

Cliff Creek had a much greater nitrogen uptake length than Pioneer (Tables 8, 9), indicating low nutrient retention in Cliff Creek. This was in spite of the higher decomposition rates. However, when the nitrogen uptake rate in Cliff Creek was calculated using a nitrogen value assumed to be closer to biotic saturation (*i.e.* a lower NO_3-N concentration, near 0.1mg/L, rather than the measured concentration of 0.35 mg/l, which is presumably well above saturation), uptake rates in Cliff and Pioneer were

similar (Davis 1995). This indicates that biotic processes largely affected nitrogen uptake, because at levels well above biotic saturation, uptake was much slower than at or near biotic saturation. The greater uptake length in Cliff Creek, indicative of low retention, was inconsistent with the higher leaf pack decay rates and warrants further study.

Phosphorus uptake rates were identical, probably a result of similar in-stream concentrations and therefore similar biotic uptake. As a result, both uptake rates appeared driven by biotic demand, demand being much lower (and uptake rate slower) in the stream with background concentrations well above biotic saturation.

Benthic invertebrate (secondary) production again demonstrated Rush Creek to be the most productive and showed seasonal variation in all streams. In fact, the analysis showed that season-specific sampling may grossly over- or under-estimate the annual production, especially within a given feeding group. GPP measurements, using open-system or component chamber methods, provided estimates of primary production available to the benthic community, although the emphasis is on primary production available to scrapers. Secondary production measures of filterers, gatherers, and miners can provide insight regarding available carbon in transport (TOM) and as BOM. Research on how benthic production is affected by perturbations and human impacts and measurements of the expected range under natural conditions are needed for the application of secondary production measures to biomonitoring.

Functional Biomonitoring

Biological monitoring typically relies upon components of ecosystem structure to characterize stream conditions. Such structural analysis is applicable to biological monitoring, as data can often be gathered quickly and efficiently, and structural components certainly respond to stress and impairment. Macroinvertebrate community metrics, which are structural properties, have been used successfully to detect impacts of logging (Fore *et al.* 1996), mining (Robinson and Minshall 1995), and pollution (Barbour *et al.* 1996; Zamora-Muñoz and Alba-Tercedor 1996) upon streams.

While such analyses are an effective first step toward characterizing streams, simple determination of degradation based on structural factors is incomplete for two reasons. Firstly, structural measurements typically only classify streams and are largely unable to diagnose specific impacts, or determine the effects of those impacts upon the ecosystem as a whole. Secondly, ecosystem management requires, by definition, knowledge and understanding of both structure and function.

To address the first concern, biologists and managers must have a method of moving beyond simple classification. In short, when streams are determined to be degraded, we must next answer the questions: in what way and to what extent? (Fore *et al.* 1996). Streams that show intermediate degradation require more detailed monitoring and biologically relevant methods must be available to determine their condition. We suggest functional monitoring as a means of addressing these concerns.

The second concern for reliance on only structural monitoring is that maintenance of structure does not implicitly maintain integrity (Rodgers *et al.* 1979; Minshall 1996). Specifically, monitoring structural characteristics does not accurately quantify the

integrity of the ecosystem as a whole. Changes or even collapses in structure may certainly indicate a loss of ecosystem integrity; however, without implicit measures of function, management is directed solely toward maintenance of structural properties. Structure and function are intricately linked, but can operate independently and can respond differently to stress and impairment (Rodgers *et al.* 1979; King 1993; Stone 1995).

An additional benefit of functional biomonitoring not yet addressed is sensitivity to impact. Rodgers *et al.* (1979), measuring periphyton response to copper, dichromate, and chlorine, found functional measures (carbon fixation rates) to be statistically less variable than measures of structure (dry mass, chlorophyll -*a* content, ATP content). Less variation in data sets would allow for significant differences to be shown with smaller differences between means (Rodgers *et al.* 1979). The low variation in functional values would therefore enable better separation of moderately impacted streams from large groups of streams, a feature quite applicable to recent univariate statistical analysis in the development of biomonitoring metrics (Barbour *et al.* 1996; Royer and Minshall 1996). Whether or not the same will hole true for functional measurements in wilderness streams can be answered only with further research.

While structural analyses certainly appear more amenable to measurement than functional analyses, we have, with this study, shown that even the most complex measurements of ecosystem function such as community respiration, GPP, and nutrient processing rates can be measured in wilderness streams. This study should be a precursor to additional studies of wilderness stream function and the role of functional measures in biological monitoring.

Analysis of Structure and Function

For successful implementation in biomonitoring, functional processes must give insight into stream conditions and methods for their measurement must be both practical and accurate. In this study it first appears that independent functional measurements were not reconciled, or did not track one another or logically comply with some of the structural measurements. As an example, compared with Pioneer Creek, Cliff Creek had higher standing crops of both invertebrates and algae as well as greater secondary production, but the two streams had identical GPP values. These identical GPP values and high Cliff Creek decomposition (a component of respiration) rates would logically cause lower P/R ratios in Cliff, but the opposite was true. The reason for these seemingly illogical trends is that component measures are comparable only with other component measures, and do not by themselves reflect the functional processes of the whole stream system. Measurements of primary productivity and respiration were based on chamber measures of the algal community only, which must be considered when comparing these measures to secondary production or to respiration implied by decomposition rates.

The successful study of another functional parameter, nutrient retention (uptake rates and lengths), in Big Creek streams demonstrated the applicability of functional measures to answering such important ecological questions. Stream nutrient retention has been shown to be affected by both in-stream nutrient concentrations and biotic factors such as heterotrophic and autotrophic uptake. Structural differences in the biota (*e.g.* differences in algal species) would seemingly influence the functional process (nutrient uptake), but such biotic influence also is a function of the physical habitat templet. Habitat in this case is substrate or hyporheic surface area, since greater direct contact with

the water enables greater biotic uptake. The ability to quantify function as uptake lengths and rates allows for a further investigation into such structure-function interrelationships. We recommend that nutrient cycling be further studied in wilderness streams because of the relatively pristine state of both physical and biotic influences on nutrient uptake and the fundamental insights that therefore can be obtained.

Several additional advantages can be gained by quantifying and monitoring functional processes. One of the foremost research questions in ecology today is the degree to which changes in ecosystem structure affect function (Lamont 1995). An appropriate way to address such questions is to make long-term observations of both structure and function, observing how changes affect both and how changes in one affect the other. Functional processes may address some of the mechanisms driving structure, leading to a better understanding of the observed structure. If perturbation influences ecosystem function, presumably this will lead to a change in structure, and knowledge of predictable changes in function may elucidate the mechanisms driving changes in structure.

Understanding of ecosystem responses to stress or impairment comes largely in the form of mechanistic responses to specific environmental changes. Large-scale biomonitoring studies often compile large data sets and attempt to determine correlations using multivariate statistics such as PCA. While this approach is certainly an appropriate way to investigate large data sets to look for trends and possible causations, multivariate analysis should be viewed as the preliminary approach to a mechanistic understanding (Rodríguez and Magnan 1995). Generalizations can be made and can prove to be consistent among many studies of data collection and analysis (*e.g.* EPT pollution

intolerance, see Fore *et al.* 1996), but only the knowledge of mechanisms can fully explain such trends and allow for the prediction of responses to environmental change.

Hierarchy

The analysis was hierarchical in that lower levels (Stage I and II) simultaneously limited and were constrained by higher levels (Stages III and IV). For example, invertebrate and algal biomass (Stages I and II factors, respectively) are ultimately constrained by system productivity (Stage III), which, in turn, is constrained by solar input (Stage IV), yet also limited by nutrient availability (Stage II). While some measurements were moved to different stages for the sake of feasibility (see Recommendations section), the analysis is still hierarchical in that lower levels account for mechanistic understanding, and higher levels set boundary conditions on the lower levels.

An additional hierarchy was the spatial classification used for characterizing the streams of interest (Table 2). The streams shared biogeoclimatic characteristics. Differences in aspect, a stream system characteristic, were evident when comparing Cliff and Pioneer Creeks. Aspect was overshadowed by the flow regime of Rush Creek and so flow regime is appropriately in an upper hierarchical level. Reach systems differed in slope and valley form. An application of a spatial hierarchical analysis is to determine if reach system parameters match what would be expected from biogeoclimatic, system, and segment characteristics. For example, a stream that shares system-scale attributes with several other streams may have very different riparian vegetation or bed material, either of which may be indicative of impairment.

The analysis was also hierarchical in that it was composed of increasing levels of intensity, complexity, and detail. This allows for lower levels of analysis (Stages I and II) to be implemented routinely and the more advanced levels to be added, if necessary, for better characterization of stream ecosystems. A benefit of such a hierarchical analysis is the fact that additional, more complete investigation of streams does not require separate analysis and both complements and is facilitated by earlier, lower level measures. An example would be a routine gathering of invertebrate community metrics and water chemistry (Stage I). If a given stream scores poorly, that individual site could be further investigated using additional measures of structure and function (see Wilderness Stream Assessment section).

Scale

The methods tested and refined in this report can be employed at a number of spatial scales, but are most directly applicable to segment (10^2 -10^3m) and reach (10^1-10^2m) scales (Minshall 1994). When examining stream ecosystem integrity at larger scales, such as the watershed or basin, the spatial extent of the sampling would need to be increased. It is imperative that data resolution always account for stream size, and that direct comparisons of differently-sized streams be avoided, or at least made only with the understanding of predictable differences.

Temporal scale analyses can be changed simply by utilizing the prescribed methods at varying times. Measurements can be made at multiple times of the day, at different times during the year, and for longer periods of time such as 10+ to 50+ years. Frequency would depend on the variability of the particular factors and the research

questions or management objectives addressed. All of these increases in sampling frequency would require little or no adjustment to collection or analysis techniques. Improved automation of many of the measurements would be desirable, particularly for locations where access is difficult.

Modifications to the Hierarchical Analysis

Based upon actual field testing, laboratory analysis, and data evaluation, several recommendations were made regarding the rearrangement the spatial classification (Table 14) and of factors in the four-stage hierarchical analysis (Table 15). Stream order was added to the spatial classification hierarchy and was the only change. Of the four-stage hierarchical analysis, the first two stages remained intact, with the recommendation that all Stage I measures be implemented in all streams where biomonitoring data is needed. This lowest level of monitoring (Stage I) represents the minimal information required for managers to make sound decisions based upon comparisons among streams, watersheds, and ecoregions, and measures a range of potential chemical, physical, and biological impacts. Stage II requires no additional visits to the stream and minimal additional laboratory work, and contains factors important in separating reference from mining-impacted streams. Although Stages I and II remain mostly unchanged, a few alterations and additions are recommended.

Table 14. Revised spatial hierarchical classification of the Big Creek streams.

Stream Habitat (linear spatial scale)	Defining Measures	Information Source/ Guideline	Reference
Biogeoclimatic Region (10^5 m)	Regional climate Regional geology Regional topography Regional terrestrial vegetation Flow regime	Topographic maps (15') Geologic maps (15') Landsat photos Annual discharge records	(Omernik 1987) (Poff and Ward 1989)
Stream System (10^3 - 10^4 m)	Local climate Local geology Local topography Local terrestrial vegetation Thermal regime Stream order	Topographic maps (7.5') Geologic maps or literature Vegetation maps Aerial photos Annual temperature records	(Omernik and Gallant 1986) (Vannote and Sweeney 1980; Chorley *et al.* 1984; Gregory and Walling 1973)
Segment System	Tributary junctions Major geologic	Topographic maps (7.5') Ground reconaissance Low level aerial photos	
Reach System (10^1 - 10^2 m)	Channel slope Valley form Bed material Riparian vegetation	Ground survey/ mapping Topographic maps (7.5')	

Table 15. Recommended four-stage hierarchical sequence of stream environmental and biotic conditions (from Minshall 1994) based upon field implementation, laboratory analysis, and data evaluation conducted during the present study.

STAGE I	Measurement per Feature	Purpose
ENVIRONMENTAL FACTORS:		
Temperature	24-hr. maximum and minimum during warmest month of year; annual thermographs using temperature recorders	Estimate of annual maximum and diel change (ΔT) ; characterization of annual or multi-year thermal regime (see Poff and Ward 1989)
Stream width/size	5 measurements of bankfull width or determination of stream order using appropriately-scaled maps	Classification of stream size
Solar Radiation	Yearly incoming PAR using Solar Pathfinder	Relative shading by vegetation and topographic features; estimate of yearly solar input, productivity
Substratum	Mean and CV of x-axis for ≥ 100 randomly selected particles	Mean particle size distribution and heterogeneity
Alkalinity Hardness pH Specific conductance Turbidity	Grab samples analyzed using standard methods	General water quality
Riparian vegetation and bank stability conditions	Vegetation type and distribution; stream bank erosion	Determination of riparian condition
BIOTIC FACTORS:		
Macroinvertebrates	RBP III metrics refined for specific ecoregions (*e.g.* Robinson and Minshall 1995)	Biotic condition indicators community structure indices
Fish (only if specifically desired)	Appropriate metrics, density and biomass estimates	Biotic condition indicators community structure indices

STAGE II		
ENVIRONMENTAL FACTORS:		
Solar radiation	Percent incoming PAR reaching stream surface at 9, 12, 3, and 6 on a clear day in summer	Daily variability of PAR
Temperature	Seasonal 30-d thermograph records, required if no annual recorders are used	Improved characterization of thermal regime and heat budgets
Discharge	Summer baseflow measure; annual discharge records using pressure transducers	Further characterization of stream size; of annual or multi-year flow regime (Poff and Ward 1989)

STAGE II (continued)	Measurement per Feature	Purpose
Substratum	Embeddedness and stability	Estimate of sedimentation and suitability of streambed for fish (egg) and invertebrate survival
Ca and Mg (optional) Nitrate-Nitrogen Phosphorus (ortho) Sulfate	Colorimetric field procedure	Delineation of main cations Principal plant nutrients Further delineation of primary anions, may be indicative of chemical impacts
BIOTIC FACTORS:		
Algae	Periphyton chlorophyll-*a* and biomass	Quantification of an important food source and biotic indicator
Benthic organic matter	Total	Quantification of an important food source
Invertebrates	Total density Total biomass Analysis by funtional feeding group	Improved indicators, estimate of 2° consumer production; definition of trophic organization; improved estimates of 2° production when coupled with previous P/B ratios

STAGE III		
ENVIRONMENTAL FACTORS:		
Solar radiation	Stream surface, mid-depth, and bottom PAR seasonally on clear days	Estimate of solar input
Temperature	Annual thermograph records using annual temperature recorders (if not included in Stage I)	Characterization of temperature regime (Poff and Ward 1989)
Discharge	Placement of stream stage height gauges; 5 seasonal instantaneous measurements (if no annual records using pressure tranducers)	Improved characterization of flow regime; permits calculation of nutrient flux data; calculation of stage height - discharge equations for Stage IV
Current velocity and depth	Measured at random locations throughout study area.	Characterization of stream habitat suitability; determination of hydraulic stress (Statzner *et al.* 1988)
Ammonia-nitrogen	Laboratory analysis of filtered samples	Further detail regarding nitrogen dynamics
Nutrient flux (N, P)	Concentration x discharge (measured 5 times during the year)	Measure of resource availability

STAGE III (continued)		
BIOTIC FACTORS:		
Algae	Diatom community metrics	Biotic condition indicator
Benthic organic matter	Partitioned into coarse and fine sizes and main sources	Refined food resource analysis
Transported organic matter	% organic matter of transport, partitioned into coarse and fine size fractions	Estimate of exported organic matter
Metabolism	Whole-system GPP, respiration, ecosystem P/R (possibly using open-system methods in future)	Measures of ecosystem function, behavior/productivity
Nutrient uptake	Nutrient addition uptake lengths	Measurement of ecosystem function/nutrient retention
STAGE IV		
ENVIRONMENTAL FACTORS:		
Discharge	Multiple measures using stage height gauges (if no annual records using pressure transducers)	Characterization of annual stream flow regime with monthly or 5 yearly measurements
BIOTIC FACTORS:		
Ecosystem P/R	Total-system metabolism using summed component/compartment values	Measure of ecosystem function, productivity, and trophic state
Nutrient spiraling	Uptake rate	Measure of ecosystem function and utilization efficiencies
Organic matter decomposition	Leaf pack decay rates	Estimate of decomposition by microbial and invertebrate detritivores
Secondary production	Monthly measurements of invertebrate standing crops	Measure of impacts on fish-food producing capability of streams; allow calculation of future productivity using established P/B ratios

Spatial Hierarchical Classification

The importance of stream size was evidenced by this study, as it influenced several factors regarding productivity and temperature. Stream size is an important determinant of many characteristics of stream ecosystem structure and function and many stream characteristics tend to change progressively and predictability with increasing stream size (Minshall *et al.* 1985; Minshall *et al.* 1983; Vannote *et al.* 1980). For this reason size (order) determination is now included in the spatial classification (Table 14). Spatial classification is the first step in wilderness stream monitoring, and is further addressed in the Wilderness Stream Analysis section.

Environmental Factors

The Stage I point measure of discharge was moved to Stage II. Stream order is determined in the spatial classification step and replaces the single measure of discharge previously used to classify size. Stage I now incorporates a measure of yearly incoming solar radiation, as it was an easy and effective way to distinguish among streams, and provided valuable insight into productivity and yearly temperature patterns. It required a single day of measurement and reasonably transported equipment (Solar Pathfinder), and conveyed a large amount of information, warranting its movement to Stage I analysis. Benthic macroinvertebrate metric analysis remains an integral part of any biological monitoring, and should be implemented with locally refined metrics (by ecoregion, *e.g.* Robinson and Minshall 1995).

Sampling of the fish community was eliminated from the procedures of regular biomonitoring for several reasons. For these wilderness streams, it provided little

information regarding stream ecosystem integrity and can be misleading where stocked populations exist. It also may require special permits in streams harboring threatened or endangered resident or anadromous fishes, as currently found in many wilderness streams. In certain instances the fish community may be an important management priority however, in which case snorkeling is an appropriate wilderness method for characterizing the fish community. Small streams should be snorkeled using the methods of Thurow (1994). Streams too large or turbid for a single snorkeler to see from bank to bank require multiple snorkelers employing the methods of Schill and Griffith (1984). We believe electrofishing to be both logistically difficult and too intrusive to be used routinely in wilderness streams. Any analysis requires locally-refined metrics (*e.g.* Chandler *et al.* 1993), although all metrics evaluated in this study scored some of the wilderness streams slightly impaired, indicating a possible need for further refinement. Although stocking may seem inappropriate in wilderness streams, it does occur and any analysis also must consider fish stocking records, particularly timing, location, and species composition.

A previous study examining important habitat metrics in Idaho streams found channel alteration to be important in distinguishing reference from mining-impacted streams. Although such physical measures were not included in the hierarchical analysis (Minshall 1994), in streams where physical impairment is suspected, additional physical measures should be incorporated, including bank stability and bank vegetation. These lend themselves to Stage I analysis. The hierarchical analysis considered riparian vegetation a defining measure for a reach system (Table 1) and so it is implied that the status of the riparian vegetation be determined (Table 14). In certain streams, riparian

vegetation may be altered from physical impairment and the degree of such alteration should be evaluated.

Stage II analysis now incorporates the previous Stage I measure of discharge (a single measure at baseflow). The 5 seasonal measures, previously Stage II, are now part of Stage III. Ca and Mg concentrations did not appear to add to information gained from Stage I total hardness measures and were eliminated. NO_3-N and PO_4-P concentrations, though they require special handling (acidification and freezing, respectively), were essential measures, as high PO_4-P concentrations can indicate impairment in mining-impacted streams (Robinson and Minshall 1995) and can be reflective of enrichment from livestock grazing. Nutrient concentrations may also have an important influence upon functional processing (uptake) rates. Measures of NO_3-N and PO_4-P could be incorporated into Stage I analysis for certain monitoring programs when nutrient enrichment is suspected.

The movement of Stage I discharge to Stage II, and subsequent movement of Stage II discharge to Stage III, allows for all Stage I and II data to be collected during a single day in the field. This makes the additional monitoring intensity of Stage II easily achievable for any stream where a Stage I analysis is performed. The additional intensity is suited to particular situations, such as mining-impacted areas, because chemical variables shown to be important (NO_3-N, PO_4-P) and suspected to be important (sulfates) are added.

Stage III discharge is now measured 5 times during the year. Placement of stage-height gauges also was moved to Stage III from Stage IV, because the placement and subsequent 5 seasonal measures during Stage III facilitates the calculation of gauge

height-discharge equations required by Stage IV. The movement also facilitates the nutrient flux analysis, as the two require the same measurement frequency and could be performed simultaneously. Other Stage III factors did little to distinguish among the streams of this study for biomonitoring purposes. Cumulative degree days need only be directly measured for leaf pack decay measurement. Physical measures of depth and hydraulic shear may be of interest when studying the effects of specific impacts (*e.g.* trail crossing, grazing, logging), but need not be included otherwise.

Biotic Factors

Functional analysis was changed to encompass whole-system functional measures (nutrient uptake lengths) at an earlier stage (III) than component or chamber measures of GPP, P/R, and nutrient uptake rates (Stage IV). Ideally, whole system metabolism (GPP, respiration, P/R) could be determined using open-system methods (*e.g.* Marzolf *et al.* 1994) and incorporated into Stage III as well, with chamber GPP measurements remaining in Stage IV. The fact that physical reaeration dominates high gradient wilderness streams makes accurate estimates of metabolism largely dependent upon proper calculation of physical reaeration (Genereux and Hemond 1993), so research is needed to develop methods for directly determining reaeration coefficients under wilderness conditions.

If methods for determining reaeration improve, open-system metabolism measures (GPP, respiration, P/R) could also be gained using a Stage III analysis. Until then, small stream metabolism study requires component measures, which are Stage IV procedures, because of the time, training, and equipment required. The hierarchy is

altered somewhat, with the whole-system parameters being measured earlier than component part, but whole-system measures are more reasonable logistically, and if unusual values result, Stage IV could be implemented to examine each component separately.

Leaf pack decay rate measurement required seven visits: an initial collection and six removals after 1,2,3,10,20, and 30 days (Davis *et al.* submitted). A less intensive analysis is possible and requires fewer visits. Where at least two visits within a single month are possible, placement and a single removal would provide measurements of decomposition. While this would provide less complete information about decay rates, streams in which leaves were removed after the same number of days could be compared. The use of a standard leaf type, collected locally and weighed prior to any wilderness stream visits would eliminate an initial collection trip.

Analysis of secondary production was the most intensive procedure in the analysis, requiring monthly invertebrate collection, taxonomy, and biomass measurement. Such intensive analysis may not be feasible for biomonitoring purposes, unless detailed knowledge of energy and organic matter pathways are required. Five sampling periods throughout the year (coinciding with 5 Stage III discharge measurements) would provide an idea of seasonal production differences and would be better than 5 samples taken throughout a three month period. The five yearly samples would preclude cohort production interval calculations, which must be taken into consideration. Another biological monitoring option is to complete secondary production analysis once for a given stream, and to use seasonal biomass and previous P/B ratios to calculate production.

Additional Thermal and Flow Regime Analysis

Determining stream size was important partly because of predictable longitudinal trends in certain physical and biological characteristics of stream ecosystems. Two important influences upon these trends are thermal regimes and flow regimes. Temperature and flow are two of the most important environmental characteristics influencing stream ecosystem structure and function (Vannote and Sweeney 1980; Poff and Ward 1989). Management decisions based upon such characteristics of structure and function require knowledge of the flow and temperature regimes and how these characteristics affect structural and functional characteristics. In short, detailed analyses of flow and temperature regimes allow the examination of the intermediate level between large-scale disturbance (*e.g.* mining) and community response (*e.g.* benthic macroinvertebrates). While determination of stream size is an important step in estimating generalized temperature and flow characteristics, accurate characterization of individual streams requires detailed information regarding these two important environmental variables. Because of their influence on many structural and functional characteristics of stream ecosystems, we recommend that temperature and flow characteristics be determined at the level of Stage I or II analysis. provided that long-term records of discharge and/or temperature are available.

An intensive analysis used to determine stream flow regime was outlined by Poff and Ward (1989), and allows for the calculation of many flow characteristics (*e.g.* predictability, constancy, flood frequency, etc.). As a result, flow regime can be accurately quantified and compared among streams. Knowledge of the flow regime could allow for the examination and prediction of structural and functional characteristics,

allowing for more accurate and meaningful characterization of individual streams, and better comparison between different streams. A similar analysis of a stream's temperature regime would also provide insights into the specific characteristics of the stream hydrology and resultant invertebrate hydraulic habitat. An analysis was not performed for the present study because of a lack of multi-year temperature data for all streams.

Proper determination of Stage III discharge (placement and calibration of stage height gauges) is advantageous to long-term monitoring, as once gauges are placed and calibrated, discharge at a given stream can be determined by simple observation for as long as the gauges remain in place and adjacent channel morphology remains unchanged. This would allow for extensive characterization of the flow regime (Poff and Ward 1989). Placement of the gauges initially requires transport and installation of equipment and, once gauges are placed, repeated measurements of discharge are required to determine the relationship between stage height and discharge (Davis *et al.* submitted).

An optional method for obtaining more detailed analyses of stream thermal and flow regimes involves the placement temperature recorders and pressure transducers, both of which can provide the long-term continuous data needed (Davis *et al.* submitted). Such recorders can obtain year-long data sets. The annual thermographs gained by this analysis permit calculation of Stage I minimum and maximum temperatures, Stage II mean daily temperatures, Stage III cumulative degree days, Stage IV leaf pack decay rates (which requires degree days for standardization), and would facilitate extensive thermal characterization of streams (Vannote and Sweeney 1980; Poff and Ward 1989).

Temperature recorders provide a method for gaining a large amount of data with little effort and cost ($135, Onset Computer Corporation, Pocasset, MA).

Where a budget allows for the expense and a stream is visited annually, placement of a temperature recorder and/or pressure transducer should be incorporated into Stage I or II. Another thermal regime option is the placement of temperature recorders in a few streams representative of given areas and cross-calibration among a larger array of streams using a few actual measurements in every stream. This extrapolation would require that the influence of groundwater, snowmelt, and stream size be considered.

Wilderness Stream Analysis

An initial goal of this project was to determine the specific measurements necessary to describe conditions in a stream for scientific and/or management purposes. A hierarchy of stream ecosystem parameters or factors was devised that includes both structural and functional analyses of stream ecosystem parameters (Minshall 1994, see Tables 1 and 2). Next, the methods required for such an analysis were developed or refined for wilderness streams (Davis *et al.* submitted), implemented and analyzed (the focus subjects of this report), and the hierarchical analysis revised (Tables 14 and 15). Alhough stream sample size (n=3) precluded the use of statistical analysis to determine the factors necessary for stream characterization, the successful implementation of the Stage I - Stage IV factors permits an efficient, systematic approach to the analysis of stream ecosystems. Such an approach consists of a hierarchical and multi-stage decision-

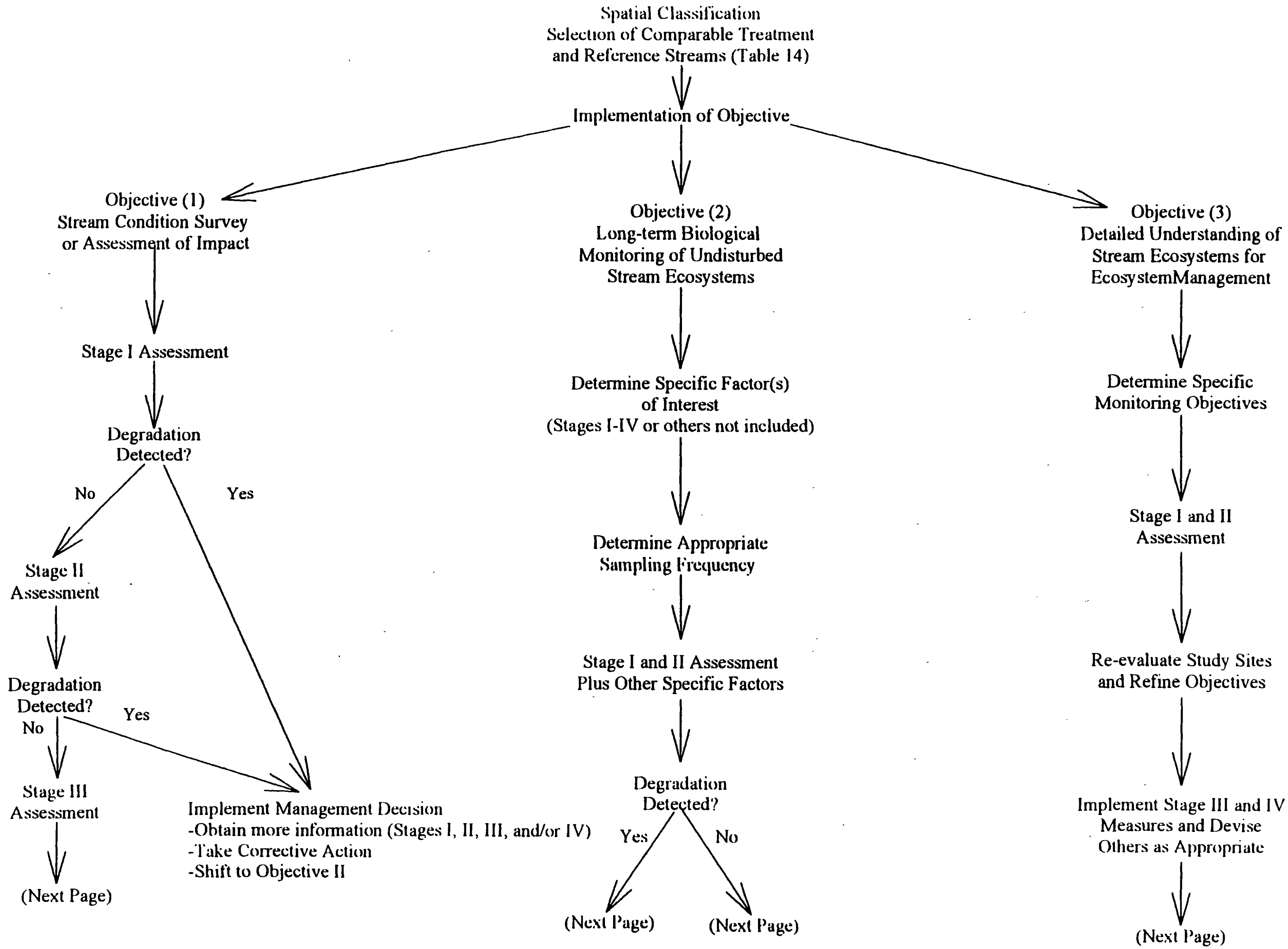
making process that requires data collection, analysis, and professional judgement at each step.

Wilderness stream monitoring can be implemented for the purposes of (1) surveying of stream condition and assessment of suspected impact, (2) long-term biomonitoring of undisturbed systems and the collection of baseline data, and (3) gaining detailed understanding of stream ecosystem conditions for appropriate management, remediation, and/or mitigation purposes. Certain factors or measures are required for any of the aforementioned objectives, while other factors or measures are more applicable to some objectives than others. As a result, a methodical approach to monitoring and data collection was developed to aid wilderness stream monitoring efforts (Fig. 14).

Regardless of the monitoring purpose, any stream of interest should first be characterized by biogeoclimatic region (Davis *et al.* submitted; Robinson and Minshall 1995) and to the level of resolution being investigated, be it stream, segment, or reach system (Table 14). Of key importance is characterization of stream size or order, a factor which influences many other characteristics. Other classification factors allow for comparison among streams and the determination of appropriate replicates or reference sites for studies of specific impact. Such factors include parent geology, aspect, and thermal and flow regimes.

Once spatial classification is complete, Stage I factors are measured, as this first stage of biological monitoring is fundamental to all three management objectives. Any assessment must utilize a balance of metrics that respond across a range of degradation and to different types of degradation (Fore *et al.* 1996) and, toward this end, Stage I assesses macroinvertebrate metrics, fundamental water chemistry measures, and habitat

Wilderness Stream Assessment



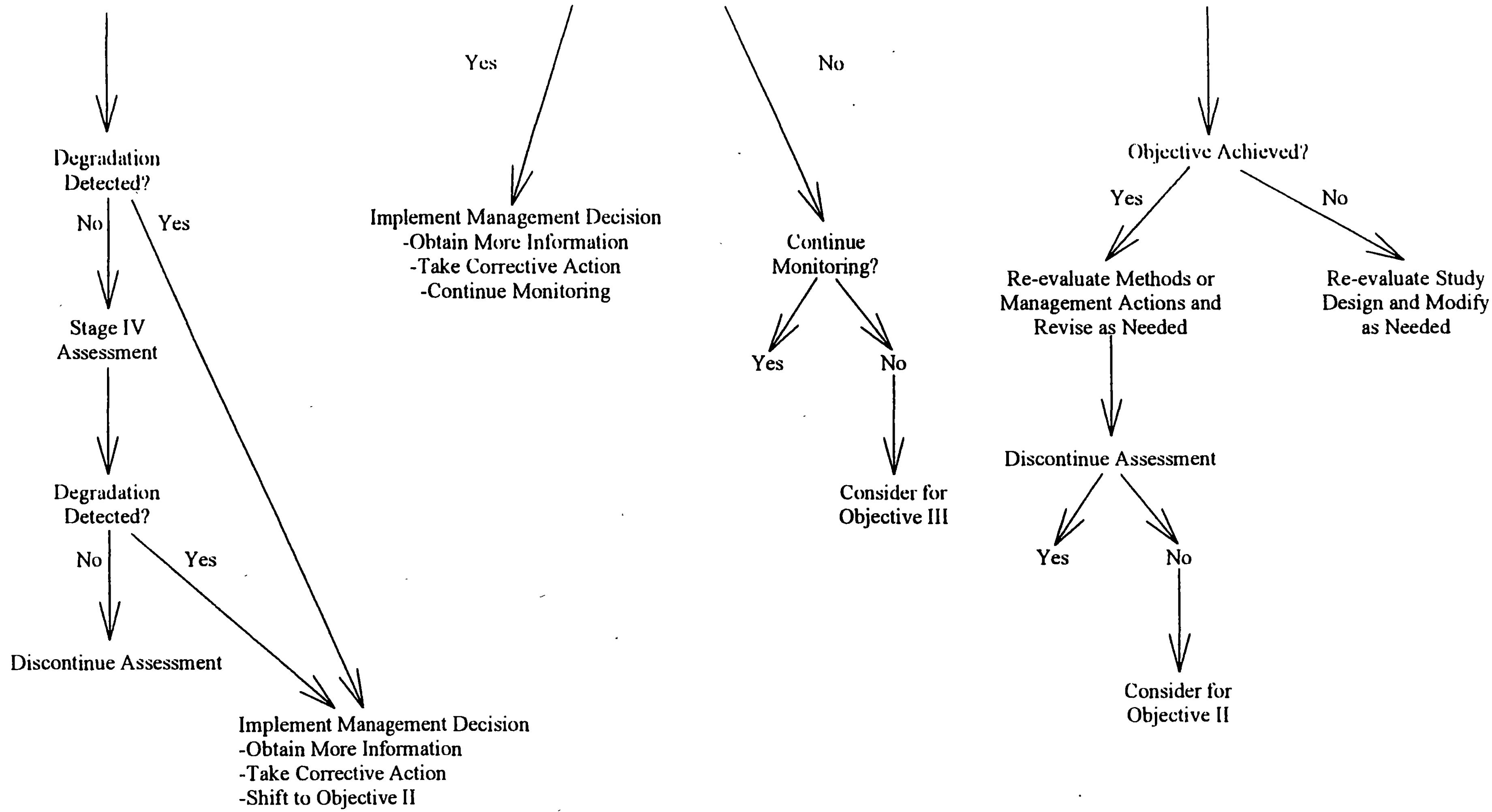


Figure 14. Wilderness Stream Assessment procedural flow chart.

characteristics. Additional monitoring stages to be implemented and factors to be measured are determined exclusively by the specific monitoring objective. The specific monitoring objective also will determine the frequency of sampling.

Survey of Stream Condition or Assessment of Impact

Management objective (1) includes large-scale regional or statewide surveys of stream ecosystems where conditions are unknown or impacts are suspected. Spatial classification is the first step in such an evaluation, and is followed by the selection of appropriate reference sites. Undisturbed reference streams, such as those used in this report, must match closely the spatial hierarchy characteristics of the streams to be surveyed or 'test' streams. Stage I analysis of all reference and test streams will then allow for a comparison of the most fundamental stream structural characteristics and investigate a range of possible impacts including chemical, physical, or biological degradation. Analysis of benthic macroinvertebrate metrics (Stage I) typically provides a great deal of information regarding stream condition (Zamora-Muñoz and Alba-Tercedor 1996; Fore *et al.* 1996; Barbour *et al.* 1996) and should be refined to suit the particular biogeoclimatic region. Stage I sampling should be conducted at least annually where potential impacts are anticipated.

Streams which show no characteristics of impairment based upon Stage I factors could then be dismissed from routine analysis, or considered for more detailed study of reference site conditions. In streams shown to be degraded (*e.g.* shows degradation of the benthic macroinvertebrate community or severe chemical degradation), the second part of objective (1) requires a determination of the suspected impact. Examples of such impacts

include runoff from salvage logging or fire suppression activities, chemical degradation from mining, and alteration of riparian and benthic habitat from grazing. Such a determination requires additional measures such as nitrate, phosphate, sulfates, and embeddedness of inorganic sediments. The exact nature of such increased analysis should be determined by professional judgment, as each situation is likely to be unique. Measures of function may be required to determine a specific impact and are needed to determine its effect upon the stream ecosystem as a whole. Analysis should progress from Stage I through Stages II, III, and IV, if necessary, to determine the specific impact(s) on the stream ecosystem (Fig. 16). For the Stage I analysis of large numbers of streams, only one visit each year is necessary. Streams that score poorly because of degradation may require more frequent sampling as analysis moves to further stages (II, III, and IV) to determine the specific impact and its effects.

Long-term Biomonitoring of Undisturbed Systems and Baseline Data Collection

The second management objective again requires spatial classification as the first step. Next, replicate streams should be selected using the same qualifications as reference streams in objective (1). This allows for monitoring to occur in a suite of streams, capturing natural variability among different stream ecosystems. The factor to be monitored, be it structural (*e.g.* macroinvertebrate diversity and algal standing crops) or functional (*e.g.* primary and secondary production, nitrogen export and/or uptake rates) is then determined. Factors other than those of Stages I-IV may be of interest and could certainly be included in an analysis. Such long-term monitoring allows for better understanding of the natural variability of stream ecosystem characteristics. All Stage I

and II factors require at least one stream visit each year, with stages III and IV adding the ability to monitor long-term variability of ecosystem function. Thus, sampling frequency is dependent upon the factor being monitored.

Detailed Understanding of Stream Ecosystems for Purposes of Ecosystem Management

The third objective is fundamental to appropriate management, remediation, or mitigation of stream ecosystems. This objective is most applicable to determining the current state of the whole stream ecosystem, and monitoring and predicting the *ecosystem* effects of known, specific impacts for purposes of ecosystem management. Objective (3) also could be used to further refine monitoring and assessment techniques and evaluate the effectiveness of past management decisions. Streams that are different sizes, in different biogeoclimatic regions, and affected by different impacts could be studied so that assessment procedures might be refined and better suited for specific cases. Past management decisions of remediation also may be evaluated for their effectiveness. Such adaptive management allows for management practices to be studied and refined while they are being implemented.

Impacts relevant to wilderness streams include fire, acid rain, mining, livestock or other large mammal grazing, and trail development. Ideally, monitoring for the effects of a specific impact would begin in advance of the impact, or historical data would exist that would enable a comparison of pre- and post-impact conditions (see Green 1979). Should no historical or pre-impact data exist, the determination and monitoring of a reference site is crucial and should be determined as in objective (1). Monitoring should progress hierarchically from Stage I to Stage IV, as the analysis was revised so that higher stages

are facilitated by earlier measurements and monitoring intensity increases progressively with each stage (Table 15). Stage I and II analyses would detect changes in invertebrate and algal biotic communities, the most important nutrients, and stream temperature and habitat characteristics. Such analysis may successfully assess the outcome of a given impact, but may not address the mechanisms responsible or the implications to the ecosystem as a whole. The hierarchical progression to Stages III and IV quantifies functional properties, allowing the investigation of such mechanisms and implications. For example, a loss of shredders from the macroinvertebrate community may be structurally documented, but the ecosystem effect of slower leaf decomposition and slower carbon turnover would not. The goal of ecosystem managers should be to understand the exact *ecosystem* effects of specific impacts, allowing for the prediction of ecosystem responses and the avoidance of ecosystem loss of integrity.

Multiple evaluations in a given year are needed to understand temporal variability of stream ecosystem structural and functional properties. This hierarchical assessment facilitates the investigation of temporal trends. A specific example is the progression from macroinvertebrate metric calculation (Stage I) to secondary production analysis (Stage IV). The collection and identification of monthly or seasonal samples needed to calculate invertebrate production translates to additional metric determinations with minimal additional work.

Recommendations For Future Research

Any intensive analysis such as conducted during this study generates many additional research questions which were addressed earlier in the Discussion. Of particular interest is the effectiveness of the revised hierarchical analysis, specifically a statistical analysis determining which factors best characterize streams. Investigation of more streams would permit the full determination of a refined set of measurements based on statistical analysis. Measurements conducted in a larger number of streams would additionally provide greater understanding of functional processes in wilderness streams and allow for a proper investigation of the role of functional biomonitoring. Should 20-30 streams be investigated for all four stages, natural variability of wilderness streams would be far better understood, the relative merits of structural versus functional measures more clearly delineated, and the applicability to biomonitoring made more concrete.

As discussed in the Introduction of this report, proper ecosystem management requires that managers focus on whole ecosystems and processes in an effort to sustain ecosystem integrity (Overbay 1992; Kessler *et al.* 1992; Minshall 1996). These processes which help to define ecosystems and maintain ecosystem integrity must be quantified for proper understanding and management. Functional biomonitoring allows for managers to measure these processes, assess the functional integrity of stream ecosystems, and thereby move beyond the structural analysis of typical biomonitoring procedures. This study demonstrated the feasibility of performing such functional analysis in wilderness streams utilizing the methods of Davis *et al.* (submitted), and the next step is the further

investigation of the role of ecosystem function in biomonitoring and the implementation of functional analysis in a greater number of streams.

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Appendix I. Site location and description for Big Creek wilderness streams.

	Cliff	Pioneer	Rush
Elevation (m)	1196	1165	1171
Latitude	45°07'N	45°06'N	45°07'N
Longitude	114°51'W	114°51'W	114°51'W
Township	T20N	T20N	T20N
Range	R13E	R13E	R13E
Section	2	3	3

Appendix B. Benthic macroinvertebrate abundance and biomass in Cliff, Pioneer, and Rush Creeks, July 1994.

CLIFF CREEK JULY 1994	Sample 1		Sample 2		Sample 3		Sample 4		Sample 5	
	#	mg	#	mg	#	mg	#	mg	#	mg
PREDATORS:										
Atherix variagata			1	0.562					1	0.326
Braconidae	1	0.111								
Ceratapogonidae					1	0.091				
Dicronota sp.			1	0.176					1	0.177
Hexatoma sp.			1	0.031						
Hydracarina	2	0.057	1	0.024	5	0.153	2	0 064	3	0 1
Megarcys sp.	3	0.835	5	0.169	5	1 323	1	0.506	3	1.264
Nematoda	1	0.021								
Oreogoton sp.			1	0.063			2	0.094	1	0.022
Rhyacophila sp. pupae					1	0.327	2	5.348		
Suwallia sp.	2	0.577	6	1.028	5	1.32	3	0.572	1	0.269
Turbellaria			2	1.432	1	0.016	1	0.611		
Scelionidae	1	0.047								
GATHERERS:										
Ameletus sp.			1	0.011	5	0.479				
Chelifera sp.			5	0.279	4	0.174	8	0.354	5	0.343
Collembola							1	0.012		
Dixa sp			2	0.074						
Doliphilodes sp.			41	3.114	1	0.131	2	0.119	23	1.572
E inermis			4	0.742	1	0.076				
Erioptera					1	0.291				
Heterlimnius sp.	14	0.831	9	0.617	24	1.045	27	1.189	7	0.654
Narpus sp					1	0.182				
Optioservus sp.									2	0.019
Paraleptophlebia sp.	2	0.542	1	0.014	1	0.03	1	0.017	1	0.024
Rhyac. acropedes	2	0.539			7	1.845	3	0.762	11	9.826
Serratella tibialis	11	1.609	10	1.289	1	0.2	6	0.768	32	4.334
SCRAPERS.										
Baetis bicaudatis	91	5.718	233	15.945	28	1.601	60	4.353	150	10.354
Cynigmula sp.	20	8.358	7	0.543	10	7.67	16	4.388	15	1.874
Drunella coloradensis	3	20.133	4	44.132			1	4.556	1	0.776
Drunella doddsi	23	16.167	32	67.8	22	1.111	39	26.137	28	48
Epeorus longimanus	27	1.629	55	4.577	8	0.446	21	1.258		
Glossosoma s.	1	0.213								
Neophylax sp.	4	1.473	1	0.344			8	2.385		
Rithrogenia robusta			24	1.76			8	0.652	12	1.011
SHREDDERS										
Capnia sp.			7	0.267	6	0.031	6	0.059	6	0.062
Lara sp	1	2.761								
Yoroperla brevis									1	0.464
Zapada sp	16	0.35	32	0.863	15	0.17	5	0.139	53	1 991
FILTERERS:										
Parapsyche elis	4	228	1	11.85					2	23.7
" " PUPAE										
Prosumulium sp	6	0.236	23	1.946	1	0.073	1	0.145	52	6.082
" " PUPAE							1	0.139		
MINERS										
Chironomidae	16	0.302	20	0.932	27	0.264	22	0.462	23	0.646
" " PUPAE	11	0.089	7	0.078	4	0.078	4	0.047	10	0.342
Oligochaeta	71	2.594	117	10.184	196	10.337	132	9.917	47	4.511
Nematamorpha			1	1.936			1	3.139		
TOTALS	333	293.192	655	172.822	381	29.484	384	68.194	491	118.767
TOTAL/m2	3583.08	3154.746	7047.8	1859.565	4099.56	317.2478	4131.84	733.7674	5283.16	1277.933

JULY mean density (/m2)	4829.088
std dev	1385.209
JULY mean biomass (/m2)	1468.652
std dev	1075.152

BY FEEDING GROUPS:	dens	std dev	biomass	std dev
Predators	152.792	47.7579	84 4316	60.0857
Gatherers	596.104	228.5835	73.3983	61.0917
Scrapers	2050.856	1134.035	657.2079	491.9078
Shredders	318.496	214.6074	15.4449	14.3494
Filterers	195.832	237.0133	585.1008	105.624
Miners	1525.768	620.5172	98.7295	50.7736

PIONEER CREEK JULY 1994	Sample 1		Sample 2		Sample 3		Sample 4		Sample 5	
	#	mg	#	mg	#	mg	#	mg	#	
PREDATORS:										
Calineuria sp.	12	9.763	15	10	4	0.287	3	0.222	3	0 213
Dicronota sp.	1	0.049	1	0.044	1	0.047	1	0.702	2	0.115
Hydracarina	3	0.096			2	0.102	3	0.102		
Megarcys sp.			1	0.508	1	0.122				
Nematoda					1	0.032	3	0.074	1	0.031
Oreogoton sp.			4	0.354	1	0.107				
Rhyacophila angelita									1	0.176
vagrita	6	0.33	3	1.871						
Staphylinidae	1	0.064			1	0.84	1	0.032		
Suwallia sp.	6	1.223	10	1.288	2	0.168	10	1 288	2	0 534
Turbellaria	12	4.843	8	2.794	1	0.092	4	2.336	4	0 467
GATHERERS.										
Ameletus sp			3	0.052						
Amiocentrus sp										
Antocha sp.	1	0.659			2	0.769				
Chelifera sp.					1	0.326				
E. inermis	10	1.345	1	0.063						
Heterlimnius sp.	13	1.074	7	0.621	4	0.232	4	0.095	5	0.637
Optioservus sp.	2	0.051			2	0.134				
Paraleptophlebia sp.	41	1.004	12	0.247	3	0.063				
Rhyac acropedes	4	0.488	3	0.457			2	1.876	1	0.107
Serratella tibialis			1	0.122			1	0.162		
SCRAPERS:										
Baetis bicaudatis	33	0.798	114	7.255	33	2.055	33	1.64	7	0.408
Cynigmula sp.	15	1.198	12	1.051	19	3.16	8	0.547	2	0.587
Drunella coloradensis	2	3.765							2	12 905
Drunella doddsi									1	12.275
Drunella spinifera									1	2.224
Epeorus longimanus	46	45	37		18		16		2	
Rithrogenia robusta							2	1.12		
SHREDDERS:										
Capnia sp	1	0.009								
Zapada sp	59	2.037	17	0.586	11	0.477	16	0.588	8	0.247
FILTERERS:										
Parapsyche elis			4	15.287	2	7 228			1	15 027
" " PUPAE	4	29.3					1	1.4		
Prosumulium sp.	10	0.824	3	0.175	3	0.633	3	0.359	3	0 836
MINERS:										
Chironomidae	77	3.608	36	1.176	20	0.447	29	1.087	12	0 153
" " PUPAE	27	1 009	8	0.169	2	0.021	8	0.261	1	0.027
Oligochaeta	41	2.734	47	2.404	37	3.152	31	1.982	38	53.8
TOTALS	427	111.271	347	46.524	171	20.494	179	15.873	97	100.769
TOTAL/m2	4594.52	1197.276	3733.72	500.5982	1839.96	220.5154	1926.04	170.7935	1043.72	1084.274

JULY mean density (/m2)	2627.592
std dev	1475.933
JULY mean biomass	634.6915
std dev	480.4556

BY FEEDING GROUPS.	dens	std dev	biomass	std dev
Predators	290.52	151.2153	88.912	83.1629
Gatherers	264.696	293.3556	22.7768	15.9733
Scrapers	867.256	587.1155	206.5662	218.3753
Shreders	243.176	228.2033	16.437	7.5702
Filterers	73.168	45.2688	152.94	14.4932
Miners	890.928	407.3481	155.0086	238.6963

RUSH CREEK JULY 1994	Sample 1		Sample 2		Sample 3		Sample 4		Sample 5	
	#	mg	#	mg	#	mg	#	mg	#	mg
PREDATORS										
Atherix variagata	5	0 753	2	0.292	13	15 491	4	5 22	3	11 831
Ceratapogonidae									1	0.094
Dicronota sp	1	1.763					1	0.536	1	0.692
Glutops sp.							1	5 164		
Hesperoperla pacifica	22	7.778	13	6.694	4	0.497	14	105.5	10	28.4
Hexatoma sp.			2	7.168			1	6.086	2	55.8
Hydracarina	29	1.301	34	1.673	22	1.591	23	0.667	35	2.373
Rhyacophila angelita	2	4 604								
Skwala sp			2	0.047					1	4.935
Suwallia sp	5	1.066	3	0.426	3	0.253	4	0.278	4	0.116
Turbellaria	1	0.006	2	0.248	2	0.179	4	0.165		
GATHERERS:										
Antocha sp	4	2.245	6	5.034	22	20.698	10	8.911	6	6.021
Chelifera sp.	1	0.054	2	0.113	3	0.794	3	0.146	3	0.419
Heterlimnius sp					3	0.066	3	0.083	4	0 057
" " ADULTS	4	1.381	4	1 591			2	0.616	2	0.73
Narpus sp	1	0.04	1	1.265			4	3.538	4	2 253
Optioservus sp.	6	0.439	16	0.812	33	1.903	31	2.34	25	1.181
" " ADULTS	2	0.801	2	0.719	3	1.072			1	0.275
Paraleptophlebia sp.	1	0.021	1	0.017			5	0.192		
Rhyac acropedes	1	0.527			3	2.194	3	45.3	3	1.627
Serratella tibialis	39	4.903	26	4.308	16	1.383	50	6.559	20	2.669
SCRAPERS:										
Baetis bicaudatus	124	8.953	140	5.616	155	7.665	90	4.615	55	6.209
Caudatella	1	0.031					2	1.613	1	0.482
Cynigmula sp.	3	1.327	4	1.174	2	1.232	2	0.836		
Drunella coloradensis	18	16.432	15	15.657	18	23.6	33	64.3	14	20.4
Drunella doddsi							1	0.021		
Drunella spinifera										
Deuterophlebiidae	1	0.104								
Epeorus longimanus	34	6.548	9	1.074	9	2.307	49	28.5		
Glossosoma s			1	0.024						
Lepidostoma sp	2	0.026	3	0.039	2	0.043	5	0.082	2	1.072
Neophylax sp.	2	4.333	1	2.764	1	0.029	1	0.129	1	0.038
Paraleuctra sp.										
Rithrogenia robusta			1	2.667						
SHREDDERS.										
Micrasema sp.					6	0.138	5	0.047	3	0.194
Pteronarcys californica	2	199.4					1	0.129		
Tipula sp.			1	0.216						
Visoka cataractae										
Zapada cinctipes	6	0.275	4	0 058	4	0.022	4	0.059	4	0.071
FILTERERS.										
Brachycentrus sp.	22	81	1	3.087	6	1.054	25	113.3		
Simulium sp.	12	0.426	1	0.011	1	0.006	12	0 617	21	1 591
MINERS:										
Chironomidae	102	5.832	131	4.791	241	12.747	262	9 99	66	4.66
" " PUPAE	32	1.206	21	0 619	33	1.636	25	0.591	22	1 316
Oligochaeta	13	0.822	57	1.432	36	6.421	31	0 682	14	1.554
TOTALS	498	354.397	506	69.636	641	103.263	731	417.212	328	157.06
TOTAL/m2	5358.48	3813.312	5444.56	749.2834	6897.16	1111.11	7865.56	4489.201	3529.28	1689.966

JULY mean density (/m2)	5819.006
std dev	1666.105
JULY mean biomass (/m2)	2370.574
std dev	2016.077

BY FEEDING GROUPS	dens	std dev	biomass	std dev
Predators	641.296	75.1661	603.1152	574 1323
Gatherers	815.608	237.8231	291.6326	255.7155
Scrapers	1725.904	528.4245	495.739	329.0264
Shredders	86.08	22.6254	431.7106	959.7163
Filterers	249.632	203.5034	704 6143	921.3314
Miners	2380.112	1094.546	116.8558	62.5637

Appendix C. Secondary production data for Cliff, Pioneer, and Rush Creeks, 1994.

CLIFF CREEK 1994

SECONDARY PRODUCTION	ANNUAL PROD	P/B	SPRING PROD	P/B	SUMMER PROD	P/B	FALL PROD	P/B	WINTER PROD	P/B	SEASON SUM
PREDATORS.											
Calineuria sp.	13	1.2									
Dicronota sp.	18	28.37	39	2.28	2	2.18	25	3.76	70	3.27	136
Megarcys sp.	210	2.45	318	3.28	185	5.82	167	3.19	202	1.01	872
Polycentropus sp.	40	4.47	16	2.65	27	2.89	43	3.09	25	2.73	111
R angelita	64	28									
Suwallia sp.	98	3.51	189	4.77	20	1.85	11	1.43	12	2.01	232
TOTAL	443		562		234		246		309		1351
P/B MEAN	3.25		3.52		4.43		3.05		1 31		
PERCENT ANNUAL PRODUCTION			42		17		18		23		
GATHERERS.											
Heterlimnius sp.	48	4.61	13	2.62	96	4.03	65	3.63	20	2.27	194
Paraleptophlebia sp.	1	3.46									
Rhyac. acropedes	224	3.85	138	1.97	219	2.03	122	2.6	113	1.85	592
Serratella inermis	6	13.99									
Serratella tibialis	59	6.2									
TOTAL	338		151		315		187		133		786
P/B MEAN	4.29		2.01		2.39		2.88		1.9		
PERCENT ANNUAL PRODUCTION			19		40		24		17		
SCRAPERS:											
Baetis bicaudatis	653	27.21	617	19	1852	24.89	206	21.52	578	23.27	3253
Cinygmula sp.	141	4.18	182	5.06	194	3.08	46	2.83	219	3.34	641
Drunella coloradensis	213	11.14	9	1.67	534	4.2	327	4.11	55	3.84	925
Drunella doddsi	1340	5.94	1295	2.65	2004	4.34	705	10.48	89	2.54	4093
Epeorus longimanus	91	4.16	670	4.45	469	3.94	48	3.67	75	2.49	1262
Neophylax sp.	43	2.39									
Rithrogena robusta	195	5.2	0	0	15	2.06	15	2.06	291	248	321
TOTAL	2676		2773		5068	0.48	1347		1307		10495
P/B MEAN	7.05		3.89		5.94		6.98		7.64		
PERCENT ANNUAL PRODUCTION			26		48		13		12		
SHREDDERS											
Lepidostoma sp.	33	2.66	105	4.62	0	0	77	3.69	12	1.58	194
Zapada cinctipes	120	5.62	48	4.76	19	2.08	48	4 08	313	6.17	428
TOTAL	153		153		19		125		325		622
P/B MEAN	4.53		4.66		2.08		3.83		5.57		
PERCENT ANNUAL PRODUCTION			25		3		20		52		
FILTERERS:											
Parapsyche elis	796	2.85	127	2.13	1387	7.32	1378	5.08	1212	3.16	4104
Prosimulium sp.	296	40	318	43	535	54	32	48	355	34	1240
TOTAL	1092		445		1922		1410		1567		5344
P/B MEAN	3.81		6.64		9.64		5.19		3.98		
PERCENT ANNUAL PRODUCTION			8		36		26		29		
MINERS:											
Chironomidae	161	9	283	11	116	15	50	11	180	7	629
TOTAL	161		283		116		50		180		629
PERCENT ANNUAL PRODUCTION			45		18		8		29		
GRAND TOTAL	4863		4367		7674		3365		3821		19227
GRAND P/B MEAN	5.21		4.07		6.12		5.2		4		
PERCENT ANNUAL PRODUCTION			23		40		18		20		

LENGTH FREQUENCY

PIONEER CREEK 1994

SECONDARY PRODUCTION	ANNUAL PROD	P/B	SPRING PROD	P/B	SUMMER PROD	P/B	FALL PROD	P/B	SEASON SUM
PREDATORS:									
Calineuria sp.	206	4.16	112	1.6	473	4.37	100	1.94	685
Dicronota sp.	14	1.7	30	1.83	4	1.78	8	4.38	42
Megarcys sp.	144	2.39	3	2.05	4	2.3	48	0.59	55
R. angelita	6	1.79	14	2.16	5	2.3	2	1.45	21
Suwallia sp.	55	2.26	56	2.31	55	2.53	90	2.8	201
TOTAL	425		215		541		248		1004
P/B MEAN	2.92		1.81		3.97		1.47		
PERCENT ANNUAL PRODUCTION			21		54		25		
GATHERERS.									
Heterlimnius sp.	55	3.77	43	3.33	62	4.14	80	3.71	185
Paraleptophlebia sp.	39	4.52	6	2.81	50	18.13	14	2.87	70
Rhyac. acropedes	56	2.82	106	2.98	41	3.29	14	1.68	161
Serratella inermis	6	1.64							
TOTAL	156		155		153		108		416
P/B MEAN	3.34		3.06		5.07		3.11		
PERCENT ANNUAL PRODUCTION			37		37		26		
SCRAPERS:									
Baetis bicaudatis	525	12.96	748	11.43	297	14.05	319	10.37	1364
Cinygmula sp.	118	3.17	127	2.43	128	3.28	91	3.56	346
Drunella coloradensis	136	9.01	56	4.28	283	10.29	27	2.46	366
Drunella doddsi	86	3.71							
Epeorus longimanus	416	10.55	373	9.08	827	14.32	64	7.56	1264
Rithrogena robusta	115	2.8	122	2.22			69	2.85	191
TOTAL	1396		1426		1535		570		3531
P/B MEAN	7.1		6.29		10.56		5.7		
PERCENT ANNUAL PRODUCTION			40		43		17		
SHREDDERS.									
Zapada cinctipes	205	5.64	67	9.33	97	8.47	540	8.06	704
TOTAL	205		67		97		540		704
PERCENT ANNUAL PRODUCTION			9		14		77		
FILTERERS:									
Parapsyche elis	659	3.26	834	4.68	528	3.42	1410	5.42	2772
Prosimulium sp.	204	37	253	40	419	48	192	43	864
TOTAL	863		1087		947		1602		3636
P/B MEAN	4.16		5.89		5.81		6.05		
PERCENT ANNUAL PRODUCTION			30		26		44		
MINERS.									
Chironomidae	252	8	531	10	282	13	139	10	952
TOTAL	252		531		282		139		952
PERCENT ANNUAL PRODUCTION			56		30		14		
GRAND TOTAL	3297		3481		3555		3207		10243
GRAND P/B MEAN	4.96		5.43		7		4.95		
PERCENT ANNUAL PRODUCTION			34		35		31		

RUSH CREEK 1994 SECONDARY PRODUCTION	ANNUAL PROD	P/B	SPRING PROD	P/B	SUMMER PROD	P/B	FALL PROD	P/B	WINTER PROD	P/B	SEASONA SUM
PREDATORS:											
Atherix variagata	99	2.59	136	3 41	255	3.56	181	3.87			572
Dicronota sp.	329	14.98	330	52.41	258	31 32	1607	52.27	368	30 32	2563
Hesperoperla pacifica	1124	4.45	1841	5.6	1066	3.01	649	3.07	93	1 49	3649
Hexatoma sp.	96	0.45	109	1 08	196	1.04	289	1 2			594
Skwala sp	37	1.33	40	1 43	18	2.4	54	1 43			112
Suwallia sp.	31	2.54	33	3.27	21	2.58	44	2 75	29	2.19	127
TOTAL	1716		2489		1814		2824		490		7617
P/B MEAN	3.03		4.84		2.84		4.84		5.58		
PERCENT ANNUAL PRODUCTION			33		24		37		6		
GATHERERS.											
Antocha sp.	111	3.35	169	5.56	453	7 11	9	2.96	2	2 72	633
Heterlimnius sp.	15	2.65	4	1.86	23	3.26	9	2.56	12	2.67	48
Narpus	10	0.93	24	1.33	40	1 72	18	1 56			82
Optioservus sp.	277	10.21	25	2.13	189	4.57	23	0.89	15	1 54	252
Paraleptophlebia sp.	4	6.54									
Rhyac. acropedes	47	5.78	70	9 17	75	5.21					145
Serratella inermis	125	4.33	73	2.67	131	2.78	105	3.21	40	15 98	349
TOTAL	589		365		911		164		69		1509
P/B MEAN	5.15		3.75		4.63		2.14		3 95		
PERCENT ANNUAL PRODUCTION			24		60		11		5		
SCRAPERS											
Baetis bicaudatis	3313	34.43	4456	31.87	3466	29.74	2378	28.45	1413	23.37	11713
Caudatella	17	6.45	43	6.06	24	4.8	2	2.46			69
Cinygmula sp.	1430	11.63	2011	13.6	115	3.67	369	4 89	1233	5.76	3728
Drunella coloradensis	348	5.62	143	3.56	659	3.78	4	4 13	14	3.11	820
Epeorus longimanus	365	11.93	431	7.31	303	5.13	15	4 52	4	2.59	753
Neophylax sp.	53	2.78	121	7 77	103	2.95	24	2.73			248
TOTAL	5526		7205		4670		2792		2664		17331
P/B MEAN	16.57		17.6		11.09		16.14		9 49		
PERCENT ANNUAL PRODUCTION			42		27		16		15		
SHREDDERS.											
Capnia sp.	209	41.1	282	30.24	0	0	2	0 77	34	3 22	318
Lepidostoma sp.	57	2.42	19	3	6	2.21	36	1 11	44	1 03	105
Pteronarcys californica	44	0.27	215	0 82	145	1 14					360
Zapada cinctipes	15	2.83	20	11.54	15	3.75	81	6.04			116
TOTAL	325		536		166		119		78		899
P/B MEAN	1.65		1.92		1 24		2.6		1 46		
PERCENT ANNUAL PRODUCTION			60		18		13		9		
FILTERERS.											
Arctopsyche sp.	1795	2.75	1141	1 72	801	1.67	1527	1 64	483	2.17	3952
Brachycentrus sp.	1014	6.38	1050	3.86	1129	2.01	320	2.45			2499
Simulium sp.	592	39	499	41	1596	59	1062	44	374	31	3531
TOTAL	3401		2690		3526		2909		857		9982
P/B MEAN	4.11		2.84		3.3		2.68		3.65		
PERCENT ANNUAL PRODUCTION			27		35		29		9		
MINERS.											
Chironomidae	816	10	1113	10	2441	22	271	12	764	6	4589
TOTAL	816		1113		2441		271		764		4589
PERCENT ANNUAL PRODUCTION			24		53		6		17		
GRAND TOTAL	12373		14398		13528		9079		4922		41927
GRAND P/B MEAN	5.84		6.1		5.26		4.57		6 14		
PERCENT ANNUAL PRODUCTION			34		32		22		12		